

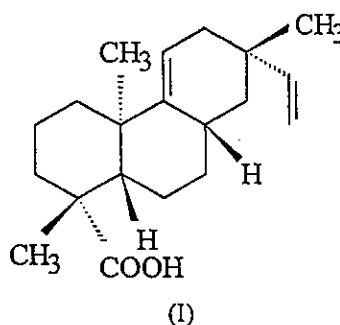
**NOVEL INTERLEUKIN-1 AND TUMOR NECROSIS FACTOR- α MODULATORS,
SYNTHESES OF SAID MODULATORS AND METHODS OF USING SAID MODULATORS**

Field of the Invention

5 The invention relates to chemical compounds and pharmaceutical compositions, including novel chemical compounds and pharmaceutical compositions thereof, useful in the treatment of various diseases and disease states. The invention also relates to methods of synthesizing natural products and novel, structurally-related chemical compounds. More particularly, the present invention relates to novel analogs of and processes for the preparation of compounds and pharmaceutical compositions
10 thereof useful in the treatment of, for example, inflammation, cancer, cachexia, cardiovascular disease, diabetes, otitis media, sinusitis and transplant rejection.

Background of the Invention

Acanthopanax koreanum Nakai (*Araliaceae*), which is found indigenously in Cheju Island, The Republic of Korea, has been used traditionally as a remedy for, for example, neuralgia, paralysis, and
15 lumbago. Various useful components, including acanthoic acid, a compound having the chemical structure of Formula (I), have been isolated from the root bark of this tree. Furthermore, certain analogs of the compound of Formula (I), for example, wherein the COOH group is replaced by a methanolic group, by a methyl-acetyl ether, by a methyl group, and by a methyl-ester have each also been isolated from the root bark of *Acanthopanax koreanum* Nakai (*Araliaceae*). See Kim, Y.H. and
20 Chung, B.S., *J. Nat. Pro.*, 51, 1080-83 (1988). (The proper chemical names of these analogs are provided in this reference.) This reference and all the other patents and printed publication cited herein are, in their entirety, incorporated by reference herein.



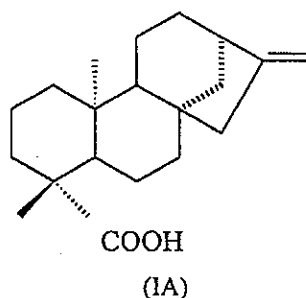
25 The compound of Formula (I), also known as acanthoic acid, has been reported to have certain pharmacological effects, including, for example, analgesic and anti-inflammatory activity. The compound of Formula (I) also exhibits very low toxicity; 1000 mg/kg is the minimum lethal dose

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(MLD) when administered to a rat. See Lee, Y.S., "Pharmacological Study for (-)-Pimara-9(11),15-Diene-19-oic Acid, A Component of *Acanthopanax koreanum* Nakai," Doctorate Thesis, Dept. of Pharmacy, Seoul National University, Korea (1990). The compound of Formula (I) and/or its naturally-occurring analogs, may exhibit these known pharmacological effects by inhibiting leukocyte migration and prostaglandin E_2 (PGE₂) synthesis, and is a suspected effector of both Interleukin-1 (IL-1) and Tumor Necrosis Factor- α (TNF- α) production. Additionally, a process for the preparation of acanthoic acid, and use of the acanthoic acid for treatment of immune disease is described in International Patent Publication WO 95/34300 (Dec. 21, 1995).

Also, the compound of Formula (IA), kauranoic acid, and the corresponding methyl-ester analog of the compound of Formula (IA), as well as methanolic reduction analogs of the compound of Formula (IA) have been isolated from the root bark of *Acanthopanax koreanum* Nakai (*Araliaceae*). See Kim, Y.H. and Chung, B.S., *J. Nat. Pro.*, 51, 1080 (1988). (The proper chemical name of kauranoic acid, (-)-kaur-16-en-19-oic acid, and of the known analogs of kauranoic acid are provided in this reference.)



Tumor Necrosis Factor- α (herein "TNF- α " or "TNF") and/or Interleukin-1 (herein "IL-1") are involved in various biochemical pathways and, thus modulators of TNF- α and/or IL-1 activity or production, especially novel modulators of TNF- α and/or IL-1 activity or novel compounds that influence the production of either IL-1 or TNF- α , or both, are highly desired. Such compounds and classes of compounds would be valuable in maintaining the human immune system and in treating diseases such as for example, tuberculous pleurisy, rheumatoid pleurisy, and diseases not conventionally considered to be immune disorders, such as cancer, cardiovascular disease, skin redness, viral infection, diabetes, and transplant rejection.

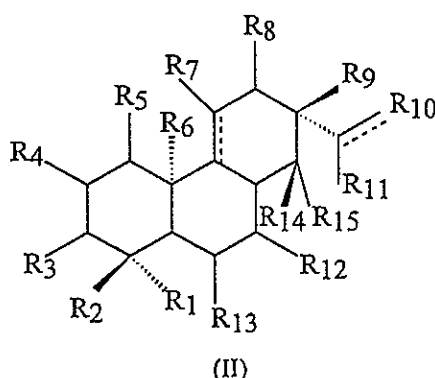
Although numerous approaches to regulate the production of Tumor Necrosis Factor- α and the interleukins are known, novel approaches, compounds, and pharmaceutical formulations to regulate the

production of Tumor Necrosis Factor- α and interleukins are highly desirable and have been long sought by those of skill in the art.

Summary of the Invention

Accordingly, it is an object of the present invention to provide processes for the synthetic and semi-synthetic preparation of the compounds of Formulae (I) and (IA) and their structural analogs, including novel analogs, of the compounds of Formulae (I) and (IA).

The compounds of the present invention include, for example, compounds having the chemical structure of Formula (II) and compounds having the chemical structure of Formula (IIA). Regarding compounds having the chemical structure of Formula (II), the invention includes:



wherein the R groups are defined as follows: If any R₃-R₅, R₇, R₈, R₁₁-R₁₃ is not hydrogen, R₂ or R₆ or R₉ is not methyl, or R₁₀ is not CH₂, then R₁ is selected from the group consisting of hydrogen, a halogen, COOH, C₁-C₁₂ carboxylic acids, C₁-C₁₂ acyl halides, C₁-C₁₂ acyl residues, C₁-C₁₂ esters, C₁-C₁₂ secondary amides, (C₁-C₁₂)(C₁-C₁₂) tertiary amides, C₁-C₁₂ alcohols, (C₁-C₁₂)(C₁-C₁₂) ethers, C₁-C₁₂ alkyls, C₁-C₁₂ substituted alkyls, C₂-C₁₂ alkenyls, C₂-C₁₂ substituted alkenyls, and C₅-C₁₂ aryls; however, if all R₃-R₅, R₇, R₈, R₁₁-R₁₃ are hydrogen, R₂, R₆, and R₉ are each methyl, and R₁₀ is CH₂, then R₁ is selected from hydrogen, a halogen, C₁-C₁₂ carboxylic acids, C₁-C₁₂ acyl halides, C₁-C₁₂ acyl residues, C₂-C₁₂ esters, C₂-C₁₂ secondary amides, (C₁-C₁₂)(C₁-C₁₂) tertiary amides, C₂-C₁₂ alcohols, (C₁-C₁₂)(C₁-C₁₂) ethers other than methyl-acetyl ether, C₂-C₁₂ alkyls, C₁-C₁₂ substituted alkyls, C₂-C₁₂ alkenyls, C₂-C₁₂ substituted alkenyls, and C₂-C₁₂ aryls.

R₂ and R₉ are each separately selected from hydrogen, a halogen, C₁-C₁₂ alkyl, C₁-C₁₂ substituted alkyls, C₂-C₁₂ alkenyl, C₂-C₁₂ substituted alkenyl, C₂-C₁₂ alkynyl, C₁-C₁₂ acyl, C₁-C₁₂ alcohol, and C₅-C₁₂ aryl.

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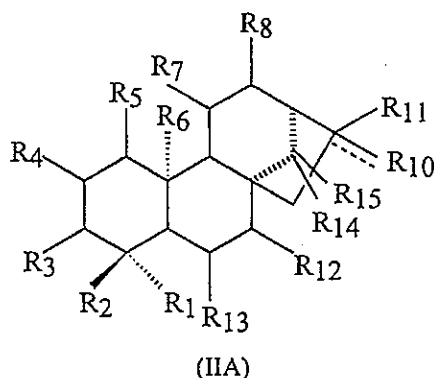
R_3 - R_5 , R_7 , R_8 , and R_{11} - R_{13} are each separately selected from hydrogen, a halogen, C_1 - C_{12} alkyl, C_1 - C_{12} substituted alkyls, C_2 - C_{12} alkenyl, C_2 - C_{12} substituted alkenyl, C_2 - C_{12} alkynyl, and C_5 - C_{12} aryl. In particularly preferred embodiments, R_{11} is a C_1 - C_6 alkyl, or C_1 - C_6 substituted alkyl, and all other R groups are hydrogen.

- 5 R_6 is selected from hydrogen, a halogen, C_1 - C_{12} alkyl, C_1 - C_{12} substituted alkyls, C_2 - C_{12} alkenyl, C_2 - C_{12} substituted alkenyl, and C_2 - C_{12} alkynyl.

R_{10} is selected from hydrogen, a halogen, CH_2 , C_1 - C_6 alkyl, C_1 - C_6 substituted alkyl, C_2 - C_6 alkenyl, C_2 - C_6 substituted alkenyl, C_1 - C_{12} alcohol, and C_5 - C_{12} aryl.

- 10 R_{14} and R_{15} are separately selected from hydrogen, a halogen, CH_2 , C_1 - C_6 alkyl, C_1 - C_6 substituted alkyl, C_2 - C_6 alkenyl, C_2 - C_6 substituted alkenyl, C_1 - C_6 alcohol, and C_5 - C_6 aryl.

Regarding compounds having the chemical structure of Formula (IIA), the invention includes:



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wherein, if any R_3 - R_5 , R_7 , R_8 , R_{11} - R_{13} is not hydrogen, R_2 or R_6 is not methyl, R_{10} is not CH_2 , or if it is not true that R_{10} is CH_2OH and R_{11} is OH , then R_1 is selected from the group consisting of hydrogen, a halogen, $COOH$, C_1 - C_{12} carboxylic acids, C_1 - C_{12} acyl halides, C_1 - C_{12} acyl residues, C_1 - C_{12} esters, C_1 - C_{12} secondary amides, $(C_1-C_{12})(C_1-C_{12})$ tertiary amides, C_1 - C_{12} alcohols, $(C_1-C_{12})(C_1-C_{12})$ ethers, C_1 - C_{12} alkyls, C_1 - C_{12} substituted alkyls, C_2 - C_{12} alkenyls, C_2 - C_{12} substituted alkenyls; but

20

if all R_3 - R_5 , R_7 , R_8 , R_{11} - R_{13} are hydrogen, R_2 and R_6 are each methyl, and R_{10} is CH_2 or CH_2OH , then R_1 is selected from hydrogen, a halogen, C_1 - C_{12} carboxylic acids, C_1 - C_{12} acyl halides, C_1 - C_{12} acyl residues, C_2 - C_{12} esters, C_1 - C_{12} secondary amides, $(C_1-C_{12})(C_1-C_{12})$ tertiary amides, C_2 - C_{12} alcohols, $(C_1-C_{12})(C_1-C_{12})$ ethers, C_2 - C_{12} alkyls, C_2 - C_{12} substituted alkyls, C_2 - C_{12} alkenyl, and C_2 - C_{12} substituted alkenyl;

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R_2 is selected from hydrogen, a halogen, C_1 - C_{12} alkyl, C_1 - C_{12} substituted alkyls, C_2 - C_{12} alkenyl, C_2 - C_{12} substituted alkenyl, C_2 - C_{12} alkynyl, C_1 - C_{12} acyl, C_1 - C_{12} alcohol, and C_5 - C_{12} aryl;

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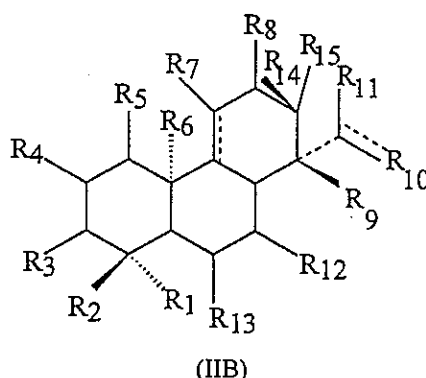
R₃, R₄, R₅, R₇, R₈, and R₁₁-R₁₃ are each separately selected from hydrogen, a halogen, C₁-C₁₂ alkyl, C₁-C₁₂ substituted alkyls, C₂-C₁₂ alkenyl, C₂-C₁₂ substituted alkenyl, C₂-C₁₂ alkynyl, and C₅-C₁₂ aryl. In particularly preferred embodiments, R₁₁ is a C₁-C₆ alkyl, or C₁-C₆ substituted alkyl, and all other R groups are hydrogen;

- 5 R₆ is selected from hydrogen, a halogen, C₁-C₁₂ alkyl, C₁-C₁₂ substituted alkyls, C₂-C₁₂ alkenyl, C₂-C₁₂ substituted alkenyl, and C₂-C₁₂ alkynyl;

R₁₀ is selected from hydrogen, a halogen, CH₂, C₁-C₆ alkyl, C₁-C₆ substituted alkyl, C₂-C₆ alkenyl, C₂-C₆ substituted alkenyl, C₁-C₁₂ alcohol, and C₅-C₁₂ aryl; and

- 10 R₁₄ and R₁₅ may be stereo-specific, and are separately selected from hydrogen, a halogen, CH₂, C₁-C₆ alkyl, C₁-C₆ substituted alkyl, C₂-C₆ alkenyl, C₂-C₆ substituted alkenyl, C₁-C₆ alcohol, and C₅-C₆ aryl.

- It is a further object of the invention to provide compounds having the chemical structure of Formula (IIB), and to provide processes for the synthetic and semi-synthetic preparation of compounds having the chemical structure of Formula (IIB). Regarding said compounds having the chemical structure of Formula (IIB), for example, the compounds herein designated TTL1, TTL2, TTL3, TTL4, and their analogs and derivatives, the invention includes:



- 20 wherein the R groups are defined as follows: R₁ is selected from the group consisting of hydrogen, a halogen, COOH, C₁-C₁₂ carboxylic acids, C₁-C₁₂ acyl halides, C₁-C₁₂ acyl residues, C₁-C₁₂ esters, C₁-C₁₂ secondary amides, (C₁-C₁₂)(C₁-C₁₂) tertiary amides, C₁-C₁₂ alcohols, (C₁-C₁₂)(C₁-C₁₂) ethers, C₁-C₁₂ alkyls, C₁-C₁₂ substituted alkyls, C₂-C₁₂ alkenyls, C₂-C₁₂ substituted alkenyls, and C₅-C₁₂ aryls.
- 25 Under these conditions, R₁ is preferably selected from COOH, C₁-C₁₂ carboxylic acids, C₁-C₁₂ acyl halides, C₁-C₁₂ acyl residues, and C₁-C₁₂ esters, and is most preferably selected from COOH and the C₁-C₆ esters.

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R₂ and R₉ are each separately selected from hydrogen, a halogen, C₁-C₁₂ alkyl, C₁-C₁₂ substituted alkyls, C₂-C₁₂ alkenyl, C₂-C₁₂ substituted alkenyl, C₂ - C₁₂ alkynyl, C₁-C₁₂ acyl, C₁-C₁₂ alcohol, and C₅-C₁₂ aryl.

R₃-R₅, R₇, R₈, and R₁₁-R₁₃ are each separately selected from hydrogen, a halogen, C₁-C₁₂ alkyl, C₁-C₁₂ substituted alkyls, C₂-C₁₂ alkenyl, C₂-C₁₂ substituted alkenyl, C₂-C₁₂ alkynyl, and C₅-C₁₂ aryl. In particularly preferred embodiments, R₁₁ is a C₁-C₆ alkyl, or C₁-C₆ substituted alkyl, and all other R groups are hydrogen.

R₆ is selected from hydrogen, a halogen, C₁-C₁₂ alkyl, C₁-C₁₂ substituted alkyls, C₂-C₁₂ alkenyl, C₂-C₁₂ substituted alkenyl, and C₂-C₁₂ alkynyl.

R₁₀ is selected from hydrogen, a halogen, CH₂, C₁-C₆ alkyl, C₁-C₆ substituted alkyl, C₂-C₆ alkenyl, C₂-C₆ substituted alkenyl, C₁-C₁₂ alcohol, and C₅-C₁₂ aryl.

R₁₄ and R₁₅ are stereo-specific and are separately selected from hydrogen, a halogen, CH₂, C₁-C₆ alkyl, C₁-C₆ substituted alkyl, C₂-C₆ alkenyl, C₂-C₆ substituted alkenyl, C₁-C₆ alcohol, and C₅-C₆ aryl.

It also will be appreciated that the various R groups, most particularly R₃, R₄, R₅, R₇, R₈, and R₁₁-R₁₃, may be chosen such that cyclic system are formed. For example, both R₁₃ and R₁₂ may be ethylene moieties and may include a covalent C-C linkage between their respective terminal carbons, generating an additional six-membered ring in the compound of Formula (IIB). As a further example, bis-cyclic rings may be formed by choosing appropriate chemical species for the various R groups, most particularly R₃, R₄, R₅, R₇, R₈, and R₁₁-R₁₃ of Formula (IIB).

The compounds of the invention include the prodrug esters of the compounds of Formulae (II), (IIA), and (IIB), and the acid-addition salts of the compounds of Formulae (II), (IIA), and (IIB), and pharmaceutical compositions comprising a therapeutically effective amount of the described compounds, including their prodrug esters and their acid-addition salts, optionally in conjunction with a pharmaceutically acceptable carrier. Such compositions are useful as, for example, anti-inflammatory analgesics, in the treatment of immune and auto-immune disorders, as anti-cancer or anti-tumor agents, and are useful in the treatment of cardiovascular disease, skin redness, viral infection, diabetes, otitis media, sinusitis and/or transplant rejection. Particularly, a pharmaceutical composition comprising a therapeutically effective amount of a compound of Formulae (II), (IIA), or (IIB), or a pro-drug ester and acid addition salt of a compound of Formulae (II), (IIA), or (IIB), may be used as an anti-cancer, anti-tumor agent, anti-viral agent, and may be useful in the treatment of cardiovascular disease, skin redness, viral infection, , diabetes, otitis media, sinusitis and/or transplant rejection.

The invention also provides novel methods of synthesizing the above described compounds and their analogs comprising the step of performing a Diels-Alder reaction reacting a diene having two or

more rings with a dienophile compound to yield a resultant compound have three or more rings; and yielding a desired synthetic compound. The Diels-Alder reaction, along with the selection of the diene and the dienophile affords flexibility in synthesizing a variety of compounds of the invention, and allows for the use of combinatorial chemistry libraries of compounds of the invention, for use
5 biological assays, including clinical trials.

Brief Description of the Figures

Certain preferred embodiments of the invention are illustrated in the Figures. The Figures merely illustrate certain preferred embodiments of the invention and/or certain preferred methods of making and/or of using the invention. The Figures are not intended to limit the scope of the invention
10 described and claimed herein.

FIG. 1 depicts the structure of acanthoic acid and acanthoic acid methyl ester, a stereo chemical view of acanthoic acid, and a skeletal-type view of certain compounds of the invention.

FIG. 2 depicts the retrosynthetic analysis and strategic bond associations of certain compounds of the invention.

15 FIG. 3 depicts selected approaches to the construction of the AB ring of certain compounds of the invention including: Wenkert's approach to the synthesis of ($\pm$) podocapric acid; Welch's approach to the synthesis of ($\pm$) podocapric acid; and DeGrot's approach to the synthesis of ($\pm$) podocapric acid.

FIG. 4 depicts a schematic synthetic scheme (Scheme 1) of the synthesis of the AB ring system of acanthoic acid and certain compounds of the invention.

20 FIG. 5 depicts a synthetic scheme (Scheme 2) by which the synthesis of acanthoic acid and certain compounds of the invention may be completed.

FIG. 6 depicts the minimized, three-dimensional model of diene 42, as described in the detailed description of the invention.

FIG. 7 depicts a synthetic scheme (Scheme 3) for the development and application of catalyst
25 49, as described in the detailed description of the preferred embodiment of the invention, an asymmetric Diels-Alder reaction.

FIG. 8 depicts a synthetic scheme (Scheme 4) for the synthesis of the compound of Formula (I) and certain compounds of the invention based on an asymmetric Diels-Alder methodology.

FIG. 9 depicts the structure activity relationship and the focus of structure activity relationship
30 studies of oleanolic acid and its derivatives and certain compounds of the invention.

FIG. 10 depicts sites identified for the structural alteration and structure activity relationship studies of Compound 1.

FIG. 11 depicts preferred, representative examples of analogs of Compound 1 for use in structure activity relationship studies and chemical biological studies.

FIG. 12 depicts certain preferred, representative derivatives of Compound 1 for photo affinity labeling studies.

FIG. 13 depicts certain preferred, representative examples of dimers and/or conjugates of Compound 1.

5 FIG. 14 depicts a complete chemical synthesis of certain compounds of the invention, identified herein as TTL1 and TTL3 in Figure 17.

FIG. 15 depicts a chemical synthesis of a preferred ¹⁴C-labeled compound of the invention, identified as TTL3 in Figure 17.

FIG. 16 depicts the complete chemical synthesis of the compound of Formula (I).

10 FIG. 17 depicts a summary of the syntheses of certain compounds of the invention, and the physical properties of these compounds. Compounds TTL1, TTL2, TTL3, and TTL4 are defined as depicted in this Figure.

FIG. 18 depicts a summary of the synthesis of Example 1.

FIG. 19 depicts the structures of (-) acanthoic acid and (+) pimaric acid.

15 FIG. 20 depicts the retrosynthetic analysis of (-) acanthoic acid of Example 1.

FIG. 21 depicts the synthetic scheme (Scheme 5) of preferred compounds of Formula (IIB) as described in Examples 1-6. The reagents, conditions, and percentage yields of each step were as follows: (a) 0.1 equiv PTSA (CH₂OH)₂, benzene, 80°C, 4 h, 90%; (b) 2.2 equiv Li, liquid NH₃, 1.0 equiv *t*BuOH, -78 to -30°C, 30 min then isoprene (excess), -78 to 50°C; 1.1 equiv NC-CO₂Me, Et₂O, -78 to 0°C, 2 h, 55%; (c) 1.1 equiv NaH, HMPA, 25°C, 3h; 1.1 equiv MoMCl, 25°C, 2h, 95%; (d) 7.0 equiv Li, liquid NH₃, -78 to -30°C, 20 min; CH₃I (excess), -78 to -30°C, 1 h, 61%; (e) 1N HCl, THF, 25°C, 15 min, 95%; (f) 1.6 equiv Li acetylide, Et₂O, 25°C, 1 h, 91%; (g) Lindlar's catalyst (20% per weight), H₂, dioxane/pyridine 10/1, 25°, 10 min 95%; (h) 4.4 equiv BF₃•Et₂O, benzene/THF4/1, 80°C, 5 h, 95%; (i) 13 equiv compound 103, neat, 8 h, 25°C, 100%; (j) 1.4 equiv NaBH₄, THF MeOH: 10/1, 25 30 min, 25°C, 94%; (k) 1.1 equiv *p*-Br-C₆H₄COCl, 1.5 equiv pyridine, 0.1 equiv DMAP, CH₂Cl₂, 25°, 2 h, 95% for compound 116, 97% for compound 117.

FIG. 22 depicts the Chem3D representation of ORTEP drawings of compound 116 and 117, showing only selected hydrogen atoms for sake of clarity.

30 FIG. 23 depicts the synthetic scheme (Scheme 6) of the tricyclic core of (-) acanthoic acid of Example 1. The reagents, conditions, and percentage yields of each step were as follows: (a) 3.0 equiv PhSH, 0.05 equiv AIBN, xylenes, 120°C, 18 h, 86%; (b) 1.1 equiv POCl₃, HMPA, 25°C, 1 h; 1.1 equiv pyridine, 150°C, 18 h 81%; (c) 3.0 equiv compound 103, 0.2 equiv SnCl₄ (1 M in CH₂Cl₂), CH₂Cl₂, -20 to 0°C, 20 h, 84%; (d) 1.4 equiv NaBH₄, EtOH, 25°C, 30 min; (e) RaneyNi (excess), THF, 65°C, 10 min 91% (over two steps); (f) 1.3 equiv Dess-Martin periodinane, CH₂Cl₂, 25°C, 30 min; (g) 2.7 equiv

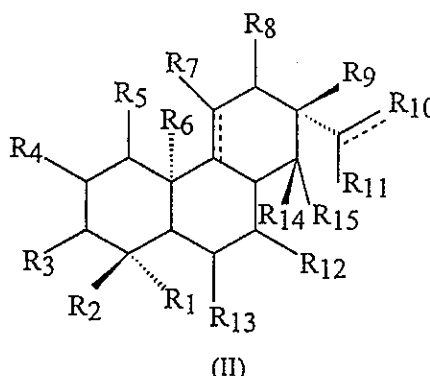
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P₃PhCH₃Br, 2.2. equiv NaHMDS (1.0 in THF), THF, 25°C, 18 h, 86% (over two steps); (h) 3.0 LiBr, DMF, 160°C, 3 h, 93%.

Detailed Description of the Preferred Embodiment

Certain compounds of the invention have the chemical structure shown in Formula (II).



The R-groups of the compound of Formula (II) may be selected in the following manner. In the event that (1) any R₃-R₅, R₇, R₈, R₁₁-R₁₃ is not hydrogen, (2) R₂, R₆ or R₉ is not methyl, or (3) R₁₀ is not CH₂, R₁ is selected from the group consisting of hydrogen, a halogen, COOH, C₁-C₁₂ carboxylic acids, C₁-C₁₂ acyl halides, C₁-C₁₂ acyl residues, C₁-C₁₂ esters, C₁-C₁₂ secondary amides, (C₁-C₁₂)(C₁-C₁₂) tertiary amides, C₁-C₁₂ alcohols, (C₁-C₁₂)(C₁-C₁₂) ethers, C₁-C₁₂ alkyls, C₁-C₁₂ substituted alkyls, C₂-C₁₂ alkenyls, C₂-C₁₂ substituted alkenyls, and C₅-C₁₂ aryls. Under these conditions, R₁ is preferably selected from COOH, C₁-C₁₂ carboxylic acids, C₁-C₁₂ acyl halides, C₁-C₁₂ acyl residues, and C₁-C₁₂ esters, and is most preferably selected from COOH and the C₁-C₆ esters.

However, in the event that (1) all R₃-R₅, R₇, R₈, R₁₁-R₁₃ are hydrogen, (2) R₂, R₆, and R₉ are each methyl, and (3) R₁₀ is CH₂, R₁ is selected from R₁ is selected from hydrogen, a halogen, C₁-C₁₂ carboxylic acids, C₁-C₁₂ acyl halides, C₁-C₁₂ acyl residues, C₂-C₁₂ esters, C₂-C₁₂ secondary amides, (C₁-C₁₂)(C₁-C₁₂) tertiary amides, C₂-C₁₂ alcohols, (C₁-C₁₂)(C₁-C₁₂) ethers other than methyl-acetyl ether, C₂-C₁₂ alkyls, C₁-C₁₂ substituted alkyls, C₂-C₁₂ alkenyls, C₂-C₁₂ substituted alkenyls, and C₂-C₁₂ aryls. Under these conditions, R₁ is preferably selected from C₁-C₁₂ carboxylic acids, C₁-C₁₂ acyl halides, C₁-C₁₂ acyl residues, and C₂-C₁₂ esters, and is most preferably a C₄-C₈ ester.

R₂ and R₉ are each separately selected from hydrogen, a halogen, C₁-C₁₂ alkyl, C₁-C₁₂ substituted alkyls, C₂-C₁₂ alkenyl, C₂-C₁₂ substituted alkenyl, C₂ - C₁₂ alkynyl, C₁-C₁₂ acyl, C₁-C₁₂ alcohol, and C₅-C₁₂ aryl. Preferably, R₂ and R₉ are each separately selected from the alkyl and alkenyl residues. Most preferably, R₂ and R₉ are each methyl residues, although one of R₂ and R₉ may be methyl and the other not methyl in preferred embodiments of the compound of Formula (II).

R_3, R_4, R_5, R_7, R_8 , and $R_{11}-R_{13}$ are each separately selected from hydrogen, a halogen, C_1-C_{12} alkyl, C_1-C_{12} substituted alkyls, C_2-C_{12} alkenyl, C_2-C_{12} substituted alkenyl, C_2-C_{12} alkynyl, and C_5-C_{12} aryl. Preferably, R_3, R_4, R_5, R_7, R_8 , and $R_{11}-R_{13}$ are each hydrogen or a C_1-C_6 alkyl, and most preferably R_3, R_4, R_5, R_7, R_8 , and $R_{11}-R_{13}$ are each hydrogen. Nevertheless, any one or several of R_3, R_4, R_5, R_7, R_8 , and $R_{11}-R_{13}$ may be hydrogen, while the others may be not hydrogen, in preferred embodiments of the compound of Formula (II).

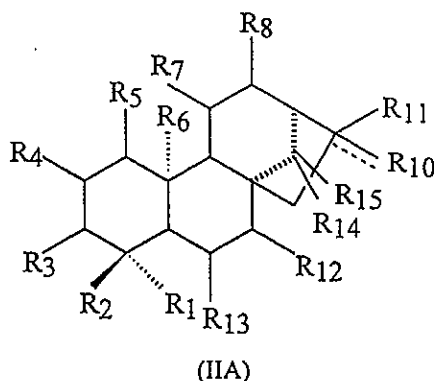
R_6 is selected from hydrogen, a halogen, C_1-C_{12} alkyl, C_1-C_{12} substituted alkyls, C_2-C_{12} alkenyl, C_2-C_{12} substituted alkenyl, and C_2-C_{12} alkynyl. Preferably, R_6 is selected from hydrogen, a halogen, C_1-C_6 alkyl. More preferably, R_6 is a C_1-C_6 alkyl, and most preferably, R_6 is methyl.

R_{10} is selected from hydrogen, a halogen, CH_2 , C_1-C_6 alkyl, C_1-C_6 substituted alkyl, C_2-C_6 alkenyl, C_2-C_6 substituted alkenyl, C_1-C_{12} alcohol, and C_5-C_{12} aryl. The bond linking R_{10} to the remainder of the compound of Formula (II) is preferably a C-C double bond, but may be a C-C single bond, a C-H single bond, or a heteroatomic single bond. Preferably, R_{10} is CH_2 or CH_2R' wherein R' is a C_1-C_6 alkyl, or a C_1-C_6 substituted alkyl. Most preferably, R_{10} is CH_2 .

R_{14} and R_{15} are separately selected from hydrogen, a halogen, CH_2 , C_1-C_6 alkyl, C_1-C_6 substituted alkyl, C_2-C_6 alkenyl, C_2-C_6 substituted alkenyl, C_1-C_6 alcohol, and C_5-C_6 aryl, with hydrogen and C_1-C_6 alkyl, C_1-C_6 substituted alkyl most preferred.

It also will be appreciated that the various R groups, most particularly R_3, R_4, R_5, R_7, R_8 , and $R_{11}-R_{13}$, may be chosen such that cyclic system are formed. For example, both R_{13} and R_{12} may be ethylene moieties and may include a covalent C-C linkage between their respective terminal carbons, generating an additional six-membered ring in the compound of Formula (II). As a further example, bis-cyclic rings may be formed by choosing appropriate chemical species for the various R groups, most particularly R_3, R_4, R_5, R_7, R_8 , and $R_{11}-R_{13}$, of Formula (II).

Certain preferred compounds of the present invention have the structure shown in Formula (IIA).



The R-groups of the compound of Formula (IIA) may be selected in the following manner. In the event that if any R_3 - R_5 , R_7 , R_8 , R_{11} - R_{13} is not hydrogen, R_2 or R_6 is not methyl, R_{10} is not CH_2 , or if it is not true that R_{10} is CH_2OH and R_{11} is OH, R_1 is selected from the group consisting of hydrogen, a halogen, $COOH$, C_1 - C_{12} carboxylic acids, C_1 - C_{12} acyl halides, C_1 - C_{12} acyl residues, C_1 - C_{12} esters, C_1 - C_{12} secondary amides, $(C_1-C_{12})(C_1-C_{12})$ tertiary amides, C_1 - C_{12} alcohols, $(C_1-C_{12})(C_1-C_{12})$ ethers, C_1 - C_{12} alkyls, C_1 - C_{12} substituted alkyls, C_2 - C_{12} alkenyls, C_2 - C_{12} substituted alkenyls. Under these conditions, R_1 is preferably selected from $COOH$, C_1 - C_{12} carboxylic acids, C_1 - C_{12} acyl halides, C_1 - C_{12} acyl residues, and C_1 - C_{12} esters, and is most preferably selected from $COOH$ and the C_1 - C_6 esters.

In the event that all R_3 - R_5 , R_7 , R_8 , R_{11} - R_{13} are hydrogen, R_2 and R_6 are each methyl, and R_{10} is CH_2 or CH_2OH , R_1 is selected from hydrogen, a halogen, C_1 - C_{12} carboxylic acids, C_1 - C_{12} acyl halides, C_1 - C_{12} acyl residues, C_2 - C_{12} esters, C_1 - C_{12} secondary amides, $(C_1-C_{12})(C_1-C_{12})$ tertiary amides, C_2 - C_{12} alcohol, $(C_1-C_{12})(C_1-C_{12})$ ethers, C_2 - C_{12} alkyls, C_2 - C_{12} substituted alkyls, C_2 - C_{12} alkenyl, and C_2 - C_{12} substituted alkenyl. Under these conditions, R_1 is preferably selected from C_1 - C_{12} carboxylic acids, C_1 - C_{12} acyl halides, C_1 - C_{12} acyl residues, and C_2 - C_{12} esters, and is most preferably a C_4 - C_8 ester.

R_2 is selected from hydrogen, a halogen, C_1 - C_{12} alkyl, C_1 - C_{12} substituted alkyls, C_2 - C_{12} alkenyl, C_2 - C_{12} substituted alkenyl, C_2 - C_{12} alkynyl, C_1 - C_{12} acyl, C_1 - C_{12} alcohol, and C_5 - C_{12} aryl. Preferably, R_2 and R_9 are each separately selected from the alkyl and alkenyl residues. Most preferably, R_2 and R_9 are each methyl residues, although one of R_2 and R_9 may be methyl and the other not methyl in preferred embodiments of the compound of Formula (IIA).

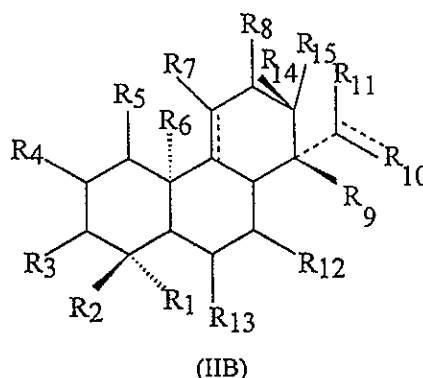
R_3 , R_4 , R_5 , R_7 , R_8 , and R_{11} - R_{13} are each separately selected from hydrogen, a halogen, C_1 - C_{12} alkyl, C_1 - C_{12} substituted alkyls, C_2 - C_{12} alkenyl, C_2 - C_{12} substituted alkenyl, C_2 - C_{12} alkynyl, and C_5 - C_{12} aryl. Preferably, R_3 , R_4 , R_5 , R_7 , R_8 , and R_{11} - R_{13} are each hydrogen or a C_1 - C_6 alkyl, and most preferably R_3 , R_4 , R_5 , R_7 , R_8 , and R_{11} - R_{13} are each hydrogen. Nevertheless, any one or several of R_3 , R_4 , R_5 , R_7 , R_8 , and R_{11} - R_{13} may be hydrogen, while the others may be not hydrogen, in preferred embodiments of the compound of Formula (IIA).

R_6 is selected from hydrogen, a halogen, C_1 - C_{12} alkyl, C_1 - C_{12} substituted alkyls, C_2 - C_{12} alkenyl, C_2 - C_{12} substituted alkenyl, and C_2 - C_{12} alkynyl. Preferably, R_6 is selected from hydrogen, a halogen, C_1 - C_6 alkyl. More preferably, R_6 is a C_1 - C_6 alkyl, and most preferably, R_6 is methyl.

R_{10} is selected from hydrogen, a halogen, CH_2 , C_1 - C_6 alkyl, C_1 - C_6 substituted alkyl, C_2 - C_6 alkenyl, C_2 - C_6 substituted alkenyl, C_1 - C_{12} alcohol, and C_5 - C_{12} aryl. The bond linking R_{10} to the remainder of the compound of Formula (IIA) is preferably a C-C double bond, but may be a C-C single bond, a C-H single bond, or a heteroatomic single bond. Preferably, R_{10} is CH_2 or CH_2R' wherein R' is a C_1 - C_6 alkyl, or a C_1 - C_6 substituted alkyl. Most preferably, R_{10} is CH_2 .

It also will be appreciated that the various R groups, most particularly R₃, R₄, R₅, R₇, R₈, and R₁₁-R₁₃, may be chosen such that cyclic system are formed. For example, both R₁₃ and R₁₂ may be ethylene moieties and may include a covalent C-C linkage between their respective terminal carbons, generating an additional six-membered ring in the compound of Formula (IIA). As a further example, bis-cyclic rings may be formed by choosing appropriate chemical species for the various R groups, most particularly R₃, R₄, R₅, R₇, R₈, and R₁₁-R₁₃ of Formula (IIA).

Certain preferred compounds of the present invention, including compounds herein designated TTL1, TTL2, TTL3, and TTL4 have the chemical structure described in Formula (IIB).



The R-groups of the compound of Formula (IIB) may be selected in the following manner: R₁ is selected from the group consisting of hydrogen, a halogen, COOH, C₁-C₁₂ carboxylic acids, C₁-C₁₂ acyl halides, C₁-C₁₂ acyl residues, C₁-C₁₂ esters, C₁-C₁₂ secondary amides, (C₁-C₁₂)(C₁-C₁₂) tertiary amides, C₁-C₁₂ alcohols, (C₁-C₁₂)(C₁-C₁₂) ethers, C₁-C₁₂ alkyls, C₁-C₁₂ substituted alkyls, C₂-C₁₂ alkenyls, C₂-C₁₂ substituted alkenyls, and C₅-C₁₂ aryls. Under these conditions, R₁ is preferably selected from COOH, C₁-C₁₂ carboxylic acids, C₁-C₁₂ acyl halides, C₁-C₁₂ acyl residues, and C₁-C₁₂ esters, and is most preferably selected from COOH and the C₁-C₆ esters.

R₂ and R₉ are each separately selected from hydrogen, a halogen, C₁-C₁₂ alkyl, C₁-C₁₂ substituted alkyls, C₂-C₁₂ alkenyl, C₂-C₁₂ substituted alkenyl, C₂ - C₁₂ alkynyl, C₁-C₁₂ acyl, C₁-C₁₂ alcohol, and C₅-C₁₂ aryl. Preferably, R₂ and R₉ are each separately selected from the alkyl and alkenyl residues. Most preferably, R₂ and R₉ are each methyl residues, although one of R₂ and R₉ may be methyl and the other not methyl in preferred embodiments of the compound of Formula (IIB).

R₃, R₄, R₅, R₇, R₈, and R₁₁-R₁₃ are each separately selected from hydrogen, a halogen, C₁-C₁₂ alkyl, C₁-C₁₂ substituted alkyls, C₂-C₁₂ alkenyl, C₂-C₁₂ substituted alkenyl, C₂-C₁₂ alkynyl, and C₅-C₁₂ aryl. Preferably, R₃, R₄, R₅, R₇, R₈, and R₁₁-R₁₃ are each hydrogen or a C₁-C₆ alkyl, and most

preferably R_3 , R_4 , R_5 , R_7 , R_8 , and R_{11} - R_{13} are each hydrogen. Nevertheless, any one or several of R_3 , R_4 , R_5 , R_7 , R_8 , and R_{11} - R_{13} may be hydrogen, while the others may be not hydrogen, in preferred embodiments of the compound of Formula (IIB).

R_6 is selected from hydrogen, a halogen, C_1 - C_{12} alkyl, C_1 - C_{12} substituted alkyls, C_2 - C_{12} alkenyl, C_2 - C_{12} substituted alkenyl, and C_2 - C_{12} alkynyl. Preferably, R_6 is selected from hydrogen, a halogen, C_1 - C_6 alkyl. More preferably, R_6 is a C_1 - C_6 alkyl, and most preferably, R_6 is methyl.

R_{10} is selected from hydrogen, a halogen, CH_2 , C_1 - C_6 alkyl, C_1 - C_6 substituted alkyl, C_2 - C_6 alkenyl, C_2 - C_6 substituted alkenyl, C_1 - C_{12} alcohol, and C_5 - C_{12} aryl. The bond linking R_{10} to the remainder of the compound of Formula (II) is preferably a C-C double bond, but may be a C-C single bond, a C-H single bond, or a heteroatomic single bond. Preferably, R_{10} is CH_2 or CH_2R' wherein R' is a C_1 - C_6 alkyl, or a C_1 - C_6 substituted alkyl. Most preferably, R_{10} is CH_2 .

It also will be appreciated that the various R groups, most particularly R_3 , R_4 , R_5 , R_7 , R_8 , and R_{11} - R_{13} , may be chosen such that cyclic system are formed. For example, both R_{13} and R_{12} may be ethylene moieties and may include a covalent C-C linkage between their respective terminal carbons, generating an additional six-membered ring in the compound of Formula (IIB). As a further example, bis-cyclic rings may be formed by choosing appropriate chemical species for the various R groups, most particularly R_3 , R_4 , R_5 , R_7 , R_8 , and R_{11} - R_{13} of Formula (IIB).

Definitions

As used herein, the term "alkyl" means any unbranched or branched, saturated hydrocarbon, with C_1 - C_6 unbranched, saturated, unsubstituted hydrocarbons being preferred, and with methyl, ethyl, isobutyl, and tert-butyl being most preferred. Among the substituted, saturated hydrocarbons, C_1 - C_6 mono- and di- and pre-halogen substituted saturated hydrocarbons and amino-substituted hydrocarbons are preferred, with perfluoromethyl, perchloromethyl, perfluoro-tert-butyl, and perchloro-tert-butyl being the most preferred. The term "substituted alkyl" means any unbranched or branched, substituted saturated hydrocarbon, with unbranched C_1 - C_6 alkyl secondary amines, substituted C_1 - C_6 secondary alkyl amines, and unbranched C_1 - C_6 alkyl tertiary amines being within the definition of "substituted alkyl," but not preferred. The term "substituted alkyl" means any unbranched or branched, substituted saturated hydrocarbon. Cyclic compounds, both cyclic hydrocarbons and cyclic compounds having heteroatoms, are within the meaning of "alkyl."

As used herein, the term "substituted" means any substitution of a hydrogen atom with a functional group.

As used herein, the term "functional group" has its common definition, and refers to chemical moieties preferably selected from the group consisting of a halogen atom, C_1 - C_{20} alkyl, substituted C_1 -

C₂₀ alkyl, perhalogenated alkyl, cyloalkyl, substituted cycloalkyl, aryl, substituted aryl, benzyl, heteroaryl, substituted heteroaryl, cyano, and nitro. Functional groups may also be selected from the group consisting of -SR_S, -OR_O, -NR_{n1}R_{n2}, -N⁺R_{n1}R_{n2}R_{n3}, -N=N-R_{n1}, -P⁺R_{n1}R_{n2}R_{n3}, -COR_C, -C(=NOR_O)R_C, -CSR_C, -OCOR_C, -OCONR_{n1}R_{n2}, -OCO₂R_C, -CONR_{n1}R_{n2}, -C(=N)NR_{n1}R_{n2}, -CO₂R_O,
 5 -SO₂NR_{n1}R_{n2}, -SO₃R_O, -SO₂R_O, -PO(OR_O)₂, -NR_{n1}CSNR_{n2}R_{n3}. Substituents of these functional groups R_{n1}, R_{n2}, R_{n3}, R_O and R_S are preferably each separately selected from the group consisting of a hydrogen atom, C₁-C₂₀ alkyl, substituted C₁-C₂₀ alkyl, cyloalkyl, substituted cycloalkyl, aryl, substituted aryl, benzyl, heteroaryl, substituted heteroaryl and may constitute parts of an aliphatic or aromatic heterocycle. R_C are preferably selected from the group consisting of a hydrogen atom, C₁-C₂₀ alkyl,
 10 substituted C₁-C₂₀ alkyl, perhalogenated alkyl, cyloalkyl, substituted cycloalkyl, aryl, substituted aryl, benzyl, heteroaryl, substituted heteroaryl and cyano.

As used herein, the terms "halogen" and "halogen atom" refer to any one of the radio-stable atoms of column 17 of the Periodic Table of the Elements, preferably fluorine, chlorine, bromine, or iodine, with fluorine and chlorine being particularly preferred.

15 As used herein, the term "alkenyl" means any unbranched or branched, substituted or unsubstituted, unsaturated hydrocarbon, with C₁-C₆ unbranched, mono-unsaturated and di-unsaturated, unsubstituted hydrocarbons being preferred, and mono-unsaturated, di-halogen substituted hydrocarbons being most preferred. The term "substituted alkenyl" means any unbranched or branched, substituted unsaturated hydrocarbon, substituted with one or more functional groups, with
 20 unbranched C₂-C₆ alkenyl secondary amines, substituted C₂-C₆ secondary alkenyl amines, and unbranched C₂-C₆ alkenyl tertiary amines being within the definition of "substituted alkyl." The term "substituted alkenyl" means any unbranched or branched, substituted unsaturated hydrocarbon. Cyclic compounds, both unsaturated cyclic hydrocarbons and cyclic compounds having heteroatoms, are within the meaning of "alkenyl."

25 As used herein, the term "alcohol" means any unbranched or branched saturated or unsaturated alcohol, with C₁-C₆ unbranched, saturated, unsubstituted alcohols being preferred, and with methyl, ethyl, isobutyl, and tert-butyl alcohol being most preferred. Among the substituted, saturated alcohols, C₁-C₆ mono- and di-substituted saturated alcohols are preferred. The term "alcohol" includes substituted alkyl alcohols, and substituted alkenyl alcohols.

30 As used herein, the term "aryl" encompasses the terms "substituted aryl," "heteroaryl," and "substituted heteroaryl" which refer to aromatic hydrocarbon rings, preferably having five or six atoms comprising the ring. The terms "heteroaryl" and "substituted heteroaryl" refer to aromatic hydrocarbon rings in which at least one heteroatom, *for example*, oxygen, sulfur, or nitrogen atom, is in the ring along with at least one carbon atom. "Aryl," most generally, and "substituted aryl," "heteroaryl," and

“substituted heteroaryl” more particularly, refer to aromatic hydrocarbon rings, preferably having five or six atoms, and most preferably having six atoms comprising the ring. The term “substituted aryl” includes mono and poly-substituted aryls, substituted with, for example, alkyl, aryl, alkoxy, azide, amine, and amino groups. “Heteroaryl” and “substituted heteroaryl,” if used separately, specifically
5 refer to aromatic hydrocarbon rings in which at least one heteroatom, for example, oxygen, sulfur, or nitrogen atom, is in the ring along with at least one carbon atom.

The terms “ether” and “alkoxy” refer to any unbranched, or branched, substituted or unsubstituted, saturated or unsaturated ether, with C₁-C₆ unbranched, saturated, unsubstituted ethers being preferred, with dimethyl, diethyl, methyl-isobutyl, and methyl-tert-butyl ethers being most
10 preferred. The terms “ether” and “alkoxy,” most generally, and “cycloalkoxy” and cyclic ether” more particularly, refer to any non-aromatic hydrocarbon ring, preferably having five to twelve atoms comprising the ring.

The term “ester” refer to any unbranched, or branched, substituted or unsubstituted, saturated or unsaturated ester, with C₁-C₆ unbranched, saturated, unsubstituted esters being preferred, with
15 methyl ester, and isobutyl ester being most preferred.

The term “pro-drug ester,” especially when referring to a pro-drug ester of the compound of Formula (I), refers to a chemical derivative of the compound that is rapidly transformed *in vivo* to yield the compound, for example, by hydrolysis in blood. The term “pro-drug ester” refers to derivatives of the compound of the present invention formed by the addition of any of several ester-forming groups
20 that are hydrolyzed under physiological conditions. Examples of pro-drug ester groups include pivoyloxymethyl, acetoxymethyl, phthalidyl, indanyl and methoxymethyl, as well as other such groups known in the art, including a (5-R-2-oxo-1,3-dioxolen-4-yl)methyl group. Other examples of pro-drug ester groups can be found in, for example, T. Higuchi and V. Stella, in “Pro-drugs as Novel Delivery Systems”, Vol. 14, A.C.S. Symposium Series, American Chemical Society (1975); and “Bioreversible
25 Carriers in Drug Design: Theory and Application”, edited by E. B. Roche, Pergamon Press: New York, 14-21 (1987) (providing examples of esters useful as prodrugs for compounds containing carboxyl groups).

The term “pharmaceutically acceptable salt,” especially when referring to a pharmaceutically acceptable salt of the compound of Formula (I), refers to any pharmaceutically acceptable salts of a
30 compound, and preferably refers to an acid addition salt of a compound. Preferred examples of pharmaceutically acceptable salt are the alkali metal salts (sodium or potassium), the alkaline earth metal salts (calcium or magnesium), or ammonium salts derived from ammonia or from pharmaceutically acceptable organic amines, for example C₁-C₇ alkylamine, cyclohexylamine, triethanolamine, ethylenediamine or tris-(hydroxymethyl)-aminomethane. With respect to compounds

of the invention that are basic amines, the preferred examples of pharmaceutically acceptable salts are acid addition salts of pharmaceutically acceptable inorganic or organic acids, for example, hydrohalic, sulfuric, phosphoric acid or aliphatic or aromatic carboxylic or sulfonic acid, for example acetic, succinic, lactic, malic, tartaric, citric, ascorbic, nicotinic, methanesulfonic, p-toluensulfonic or naphthalenesulfonic acid. Preferred pharmaceutical compositions of the present invention include pharmaceutically acceptable salts and pro-drug esters of the compound of Formulae (II), (IIA), and (IIB).

The terms "purified," "substantially purified," and "isolated" as used herein refer to the compound of the invention being free of other, dissimilar compounds with which the compound of the invention is normally associated in its natural state, so that the compound of the invention comprises at least 0.5%, 1%, 5%, 10%, or 20%, and most preferably at least 50% or 75% of the mass, by weight, of a given sample. In one preferred embodiment, these terms refer to the compound of the invention comprising at least 95% of the mass, by weight, of a given sample.

The terms "anti-cancer," "anti-tumor" and "tumor-growth-inhibiting," when modifying the term "compound," and the terms "inhibiting" and "reducing", when modifying the terms "compound" and/or the term "tumor," mean that the presence of the subject compound is correlated with at least the slowing of the rate of growth of the tumor or cancerous mass. More preferably, the terms "anti-cancer," "anti-tumor," "tumor-growth-inhibiting," "inhibiting," and "reducing" refer to a correlation between the presence of the subject compound and at least the temporary cessation of tumor growth or growth of the cancerous mass. The terms "anti-cancer," "anti-tumor," "tumor-growth-inhibiting," "inhibiting," and "reducing" also refer to, particularly in the most preferred embodiment of the invention, a correlation between the presence of the subject compound and at least the temporary reduction in the mass of the tumor. These terms refer to cancer and various malignancies in animals, specifically in mammals, and most specifically in humans.

The term "skin redness" means any skin redness, especially a chronic skin redness having a neurogenic origin, consistent with, but not limited by, its meaning in EP 7744250, which is hereby incorporated by reference herein in its entirety.

The term "viral infection" means any infection of a viral origin including rhinovirus, and preferably, but not exclusively, refers to human immunodeficiency virus (HIV), human cytomegalovirus, hepatitis A, hepatitis B, and hepatitis C viruses.

The term "cardiovascular disease" refers to the various diseases of the heart and vascular systems, including but not limited to congestive heart failure, cardiac dysfunction, reperfusion injury, and various known peripheral circulatory abnormalities. "Cardiovascular disease" refers to such diseases in animals, specifically in mammals, and most specifically in humans.

As used herein, the term "diabetes" refers to the various diseases related to elevated insulin levels, Insulin Resistance, or Diabetes, including Type 1 Diabetes, Type 2 Diabetes, and various related condition, including, but not limited to Stein-Leventhal Syndrome or Polycystic Ovary Syndrome (PCOS).

5 As used herein, the term "transplant rejection" refers to the conditions, and related symptoms known as allograft rejection, xenograft rejection, and autograft rejection, and in preferred embodiments of the invention, refers to human-human allograft rejection.

As used herein, the terms "modulator" or "modulation" refer to the capacity of a compound or course of treatment to alter the presence or production of a modulated compound, especially TNF- α or
10 IL-1, in an individual. Most preferably, "modulator" or "modulation" refer to the capacity of a compound or course of treatment to reduce the presence or production of a modulated compound.

As used herein, the terms TTL1, TTL2, TTL3, TTL4 and TTL5 refer to the specific chemical entities identified in, among other figures, Figure 17.

All other chemical, medical, pharmacological, or otherwise technical terms used herein are to
15 be understood as they would be understood by persons of ordinary skill in the art.

Interleukin-1 (IL-1)

Interleukin-1 (IL-1) is a regulatory factor which participates in a wide range of mammalian immune and inflammatory mechanisms and other defensive mechanism, especially mechanisms in the human body. See, e.g., Dinarello, D.A., *FASEB J.*, 2, 108 (1988). IL-1, first discovered as produced by
20 activated macrophages, is secreted by various cells, for example, fibroblasts, keratinocytes, T cells, B cells, and astrocytes of the brain, and has been reported to have various functions including: stimulating the proliferation of CD4+T cells, see Mizel, S.B., *Immunol. Rev.*, 63, 51 (1982); stimulating the cell-killing effect of thymic T_C cells through its binding to a T cell receptor, TCR, see McConkey, D. J., et al., *J. Biol. Chem.*, 265, 3009(1990); inducing the production of various materials participating in the
25 inflammatory mechanisms, for example, PGE₂, phospholipase A₂ (PLA₂) and collagenase, see Dejana, E., et al., *Bolid*, 69, 695-699 (1987)); inducing the production of acute-phase proteins in liver, see Andus, T., et al., *Eur. J. Immunol.*, 123, 2928 (1988)); raising blood pressure in the vascular system, see Okusawa, S., et al., *J. Clin. Invest.*, 81, 1162 (1988)); and inducing the production of other cytokines, for example, IL-6 and TNF- α , see Dinarello, C.A., et al., *J. Immunol.*, 139, 1902(1987). IL-
30 1 modulation is also known to effect rheumatoid arthritis, see Nouri, A. M., et al., *Clin. Exp. Immunol.*, 58, 402(1984); transplant rejection, see Mauri and Teppo, *Transplantation*, 45, 143 (1988); and septicemia, see Cannon, J. G., et al., *Lymphokine Res.*, 7, 457 (1988), and IL-1 may induce fever and pain when administered in large doses. See Smith, J., et al., *Am. Soc. Clin. Oncol.*, 9, 710 (1990)).

The occurrence of septicemia, arthritis, inflammations, and related conditions in animal models can be decreased by inhibiting IL-1 binding to its receptors by employing naturally occurring IL-1 receptor inhibitors (IL-1 Ra), *see* Dinarello, C. A. and Thompson, R. C., *Immunol. Today*, 12, 404 (1991), and certain methods for inhibiting the activity of IL-1 by employing particular antibodies have been proposed, *see* Giovine, D. F. S. and Duff, G. W., *Immunol. Today*, 11, 13 (1990). In case of IL-6, proliferation of myelocytes in a patient suffering from myeloma which is caused by an excessive secretion of IL-6 has been suppressed by employing antibodies against IL-6 or IL-6 receptor, *see* Suzuki, H., *Eur. J. Immuno.*, 22, 1989(1992)). The disease condition treatable according to the invention, via TNF- α and IL-1 modulation induced by the compounds of the invention, include but are not necessarily limited to the disease conditions herein described.

Tumor necrosis factor- α (TNF- α)

Human TNF- α was first purified in 1985. *See* Aggarwal, B. B.; Kohr, W. J. "Human tumor necrosis factor. Production, purification and characterization". *J. Biol. Chem.* 1985, 260, 2345-2354. Soon after, the molecular cloning of the TNF cDNA and the cloning of the human TNF locus were accomplished. *See* Pennica, D.; Nedwin, G. E.; Hayflick, J. S. et al "Human necrosis factor: precursor structure, expression and homology to lymphotoxin". *Nature* 1984, 312, 724-729. Wang, A. M.; Creasy, A. A.; Ladner, M. B. "Molecular cloning of the complementary DNA for human Tumor Necrosis Factor". *Nature* 1985, 313, 803-806. TNF- α is a trimeric 17-KDa polypeptide mainly produced by macrophages. This peptide is initially expressed as a 26-KDa transmembrane protein from which the 17-KDa subunit is cleaved and released following proteolytic cleavage by an enzyme known as TACE. This work clarified the immense and multifaceted biological implications of TNF- α and spurred the development of therapeutic approaches targeting its overproduction.

Tumor necrosis factor- α (TNF- α), is typically produced by various cells, for example, activated macrophages and fibroblasts. TNF- α has been reported to induce IL-1 production, *see* Dinarello, D.A., *FASEB J.*, 2, 108 (1988), kill the fibrosarcoma L929 cells, *see* Espevik and Nissen-Meyer, *J. Immunol. Methods*, 95, 99 (1986); to stimulate the proliferation of fibroblasts, *see* Sugarman, B. J., et al., *Science*, 230, 943(1985); to induce the production of PGE₂ and arachidonic acid, both of which may be involved in inflammatory responses, *see* Suttys, et al., *Eur. J. Biochem.*, 195, 465 (1991); and to induce the production of IL-6 or other growth factors, *see* Van Hinsbergh, et al., *Blood*, 72, 1467 (1988)). TNF- α has also been also reported to participate, either directly or indirectly, in various diseases such as infectious diseases carried by trypanosoma strains of the genus *Plasmodium*, *see* Cerami, A., et al., *Immunol. Today*, 9, 28 (1988)); autoimmune diseases such as systemic lupus erythematosus (SLE) and arthritis, *see* Fiers, W., *FEBS*, 285, 199 (1991); Acquired Immune Deficiency Syndrome (AIDS), *see* Mintz, M., et al., *Am. J. Dis. Child.*, 143, 771 (1989); septicemia, *see* Tracey, K.

J., et al., *Curr. Opin. Immunol.*, 1, 454 (1989); and certain types of infections, see Balkwill, F. R., *Cytokines in Cancer Therapy*, Oxford University Press (1989).

TNF- α and Inflammatory Response

Infection and tissue injury induce a cascade of biochemical changes that trigger the onset of perplexing reactions of the immune system, collectively referred to as inflammatory response. The evolution of this response is based, at least in part, on local vasodilation or enhancing vascular permeability and activation of the vascular endothelium, which allows white blood cells to efficiently circulate and migrate to the damaged site, thereby increasing their chances to bind to and destroy any antigens. The vascular endothelium is thought to then be activated or inflamed. Generally, inflammation is a welcomed immune response to a variety of unexpected stimuli, and as such it exhibits rapid onset and short duration (acute inflammation). Its persistent or uncontrolled activity (chronic inflammation) has, however, detrimental effects to the body and results in the pathogenesis of several immune diseases, such as: septic shock, rheumatoid arthritis, inflammatory bowel diseases and congestive heart failure. See "Tumor Necrosis Factors. The molecules and their emerging role in medicine" B. Beutler, Ed., Raven Press, N.Y. 1992, pages 1-590.

The unfolding of an effective immune response typically requires the recruitment of a variety of cells and the orchestration of a series of biological events. This complex intercellular coordination and interaction is mediated by a group of locally secreted low molecular weight proteins that are collectively called cytokines. These proteins bind to specific receptors on the cell surface and trigger signal-transduction pathways that ultimately alter gene expression in the target cells, thereby regulating an efficient inflammatory response.

Cytokines may exhibit properties of pleiotropism (a given protein exerts different effects on different cells), redundancy (two or more cytokines mediate similar functions), synergism (the combined effect of two cytokines is greater than the additive effect of each individual protein) and antagonism (the effect of one cytokine inhibiting the effect of another). To this end, some of the cytokines are pro-inflammatory (induce inflammation), while some others are anti-inflammatory (inhibit inflammation). The class of pro-inflammatory cytokines includes: interleukin-1 (IL-1), interleukin-6 (IL-6) and tumor necrosis factor-alpha (TNF- α). See "Tumor Necrosis Factors. The molecules and their emerging role in medicine" B. Beutler, Ed., Raven Press, N.Y. 1992, pages 1-590. These cytokines are secreted by macrophages shortly after the initiation of the inflammatory response and induce coagulation, increase the vascular permeability and activate the expression of adhesion molecules on vascular endothelial cells (for example, TNF- α stimulates expression of E-selection, that binds to and recruits neutrophils to the site of damage). Subsequently, and during a more systemic immune response, these cytokines act on several organs of the body, including bone marrow and liver

to ensure the increased production of white blood cells and the synthesis of appropriate hormones and acute-phase proteins. In addition, they act on the hypothalamus and induce fever, which helps to inhibit the growth of pathogens and enhances the overall immune reaction.

TNF- α and the Pathogenesis of Various Diseases and Conditions

5 As with any other cytokine, TNF- α is neither completely beneficial nor completely destructive to the host. Rather, balance of its production and regulation is maintained to ensure that the host can effectively react to invading microorganisms without compromising host well-being in the process. Being a mediator of inflammation, TNF- α helps the body in its fight against bacterial infections and tissue injuries by boosting an appropriate immune response. However, its overproduction leads to
10 chronic inflammation, has detrimental effects to the body and plays a major role in the pathogenesis of several diseases, some of which are summarized below.

Bacterial septic shock. This disease typically develops following infection by certain gram-negative bacteria, such as *E. coli*, *Enterobacter aerogenes* and *Neisseria meningitidis*. These bacteria bear on their cell walls certain lipopolysaccharides (endotoxins) that stimulate macrophages to
15 overproduce IL-1 and TNF- α , which in turn cause the septic shock. The symptoms of this condition, which are often fatal, include a drop in blood pressure, fever, diarrhea and widespread blood clotting. In the United States alone, this condition afflicts about 500,000 persons per year and causes more than 70,000 deaths. The annual cost for treating this disease is an estimated \$ 5-10 billion.

Rheumatoid Arthritis. This is the most common human autoimmune disease, affecting about
20 1% of the Western population and is a major source of disability, which in its severe form leads to death. See Szekanecz, Z.; Kosh, A. E.; Kunkel, S. L.; Strieter, R. M. "Cytokines in rheumatoid arthritis. Potential targets for pharmacological applications". *Clinical Pharmacol.* 1998, 12, 377-390. Camussi, G.; Lupin, E. "The future role of anti-tumor necrosis factor products in the treatment of rheumatoid arthritis". *Drugs* 1998, 55, 613-620. This condition is characterized by inflammation and cellular
25 proliferation of the synovium, which results in the invasion of the adjacent cartilage matrix, its subsequent erosion and ultimately bone destruction. Although the origins of this inflammatory response are poorly understood, an increased expression of TNF- α and IL-1 have been found around the area of cartilage erosion. More recently, the pathogenic role of TNF- α in this disorder has been extensively studied and experimentally verified. Furthermore, clinical data suggest that neutralization
30 of TNF- α may be a therapeutic approach to reduce the erosive process. To date, however, current therapy, while providing temporary relief does not alter the fundamental mechanisms of progress or process of the disease.

Inflammatory bowel diseases and related conditions. This class of diseases which include Crohn's disease and ulcerative colitis are debilitating disorders, characterized by chronic inflammation

of intestinal mucosa and lamina propria. Although the events that trigger their onset are unknown, they are associated with significant leukocyte infiltrate and local production of soluble mediators. TNF- α is therefore considered to be a key mediator in the pathogenesis of these conditions, either by a direct cytotoxic action or as an orchestrator of the inflammatory cascade. See, for example, Armstrong, A. M.; Gardiner, K. R.; Kirk, S. J.; Halliday, M. J.; Rowlands, B. J. "Tumour necrosis factor and inflammatory bowel disease". *Brit. J. Surgery* 1997, 84, 1051-1058. Data based on accepted animal models also supports the rationale for a therapeutic study in human IBD, aimed at reducing the effect of TNF. See Van Deventer, S. J. H. "Tumour necrosis factor and Crohn's disease" *Gut*, 1997, 40, 443.

Congestive heart failure. Activation of cytokines, and especially TNF- α , occurs in patients with chronic heart failure and acute myocardial infarction. See Ferrari, R. "Tumor necrosis factor in CHF: a double facet cytokine". *Cardiovascular Res.* 1998, 37, 554-559. Moreover, TNF- α has been demonstrated to trigger the apoptotic process in cardiac myocytes both directly (by binding to and genetically reprogramming these cells) and indirectly (through local NO production, which also leads to cell death).

HIV replication. Replication of HIV is activated by the inducible transcription factor NF- κ B, which in turn is induced by TNF- α . HIV expression can be induced by TNF in macrophage lines and T-cell clones chronically infected with the virus. Infusion of recombinant TNF in a small number of patients with AIDS-related Kaposi's sarcoma appeared to cause an increase in the HIV p24 antigen level, a marker of viral replicative activity. See "Therapeutic modulation of cytokines" CRC Press, Inc., N.Y. 1996, pages 221-236. These results provide a mechanistic basis for considering the use of a TNF blocker to reduce infectious HIV burden.

Other TNF mediated pathologies. There is an ever-increasing list of conditions in which there is some evidence that TNF is involved. "Therapeutic modulation of cytokines" CRC Press, Inc., N.Y. 1996, pages 221-236. In some cases, such as transplantation, graft-vs-host disease, and ischemia/reperfusion injury the potential mechanism of pathogenesis implicates the pro-inflammatory activity of TNF- α to a variety of tissue cells. Others, such as the suppression of insulin responsiveness in non-insulin-dependent diabetes, relate to more selective actions of TNF- α that appear to fall outside the standard pro-inflammatory model. TNF- α has been detected locally in patients afflicted with otitis media (inner ear infection, with or without effusion), *see for example*, Willett, D.N., Rezaee, R.P., Billy, J.M., Tighe, M.A., and DeMaria, T.F., *Ann. Rhinol Laryngol*, 107 (1998); Maxwell, K., Leonard, G., and Kreutzer, D.L., *Arch Otolaryngol Head Neck Surg*, vol. 123, p. 984 (Sept. 1997), and with sinusitis, *see for example* Nonoyana, T., Harada, T., Shinogi, J., Yoshimura, E., Sakakura, Y., *Auris Nasus Larynx*, 27(1), 51-58 (Jan 2000); Buehring I., Friedrich B., Schaff, J., Schmidt H., Ahrens P., Zielen S., *CLin Exp Immunol*, 109(3), 468-472, Sept 1997).

TNF- α and IL-1 Modulation As Therapeutic Approaches

Prior to the isolation of TNF- α , the employed therapeutic approaches to the above diseases were targeting the reduction of chronic inflammation and were based on steroidal and non-steroidal anti-inflammatory treatment. However, our recent understanding of TNF- α has led to the development of alternative strategies based on its selective inhibition. These general strategies are summarized below.

Steroidal treatment. This treatment, which includes the use of corticosteroids, causes the reduction in the number and the activity of the immune-system cells. The mechanism of action of the corticosteroids involves crossing of the plasma membrane and binding on receptors in the cytosol. The resulting complexes are then transported to the cell nucleus where they bind to specific regulatory DNA sequences, thereby down-regulating the cytokine production. Although currently employed, this strategy has several disadvantages since it is not specific for TNF- α but also downregulates several other cytokines that may play important roles in an effective immune reaction. Moreover, use of steroids is also implicated with the development of cancer (for example prostate cancer).

Non-steroidal anti-inflammatory treatment. This strategy includes use of compounds such as aspirin that indirectly reduce inflammation. This is usually accomplished by inhibiting the cyclooxygenase pathway by which prostaglandins and thromboxanes are produced. This action reduces the vascular permeability and provides temporary relief. To this end, this strategy does not regulate the production of cytokines and has little or no effect in diseases associated with chronic inflammation.

Engineered monoclonal anti-TNF antibodies. This strategy involves a selection of monoclonal antibodies that are capable of binding to and neutralizing TNF- α . Although the preliminary clinical studies have shown some positive results, this approach is still in its infancy and not generally accepted. One of the problems to be addressed is that the monoclonal antibodies are of murine origin and in humans they elicit anti-immunoglobulin immune responses which limit their clinical use. Recombinant engineering techniques are being pursued to create "humanized" versions of the rodent antibodies that will maintain activity against TNF- α and will be accepted more easily by the human immune system.

Use of soluble TNF- α receptors. The use of soluble receptors against TNF- α is a new therapeutic approach. Although these receptors are created to bind and neutralize TNF- α , they also enhance its activity by prolonging its lifespan in blood circulation. Furthermore, the long term immunological response to this type of treatment is being evaluated.

Gene therapy. The goal of this approach is to decrease inflammation not by decreasing the expression of TNF- α but by increasing the local production of anti-inflammatory cytokines. The treatment consists of direct injection of cDNA expression vectors encoding for anti-inflammatory

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cytokines to the inflamed area, which could antagonize the effect of TNF. The efficacy of this method is currently under investigation in preclinical studies and its long term effects on the immune response remain unknown.

- Other disease stated and conditions. Additionally, TNF- α and/or IL-1 have been more recently identified as participating in modulating angiogenic vascular endothelial growth factor (VEGF), *see* E. M. Paleolog et al., *Arthritis & Rheumatism*, 41, 1258 (1998), and may participate in tuberculous pleurisy, rheumatoid pleurisy, and other immune disorders, *see* T. Söderblom, *Eur. Respir. J.*, 9, 1652 (1996). TNF- α has also been reported to effect expression of certain cancer cell genes for multidrug resistance-associated protein (MRP) and lung resistance protein (LRP), *see* V. Stein, *J. Nat. Canc. Inst.*, 89, 807 (1997), and to participate in chronic and congestive heart failure, and related cardiovascular disease, *see* for example R. Ferrari, *Cardiovascular Res.*, 37, 554 (1998); C. Ceconi et al., *Prog. Cardiovascular Dis.*, 41, 25 (1998), and to either directly or indirectly mediate viral infection, *see* D.K. Biswas, et al., *J. Acquired Immune Defic Syndr. Hum Retrovirol.*, 18, 426-34 (1998) (HIV-1 replication); R. LeNauor, et al., *Res. Virol.*, 145, 199-207 (1994) (same); T. Harrer, et al., *J. Acquir. Immune Defic. Syndr.*, 6, 865-71 (1993) (same); E. Fietz, et al., *Transplantation*, 58 (6), 675-80 (1994) (human cytomegalovirus (CMV) regulation); D.F. Zhang, et al., *Chin. Med. J.*, 106, 335-38 (1993) (HCV and HBV infection). Furthermore, antagonists of TNF- α have also been shown useful in the treatment of skin redness of a neurogenic origin. *See* European Patent EPO-774250-B1 (to De Lacharriere et al.).
- TNF- α has also been identified as expressed at heightened levels in humans diagnosed as obese or exhibiting insulin resistance, and is thus, a modulator of diabetes. *See* Hotamisligil, G., Arner, P., Atkinson, R., Spiegelman, B. (1995), "Increased adipose tissue expression of tumor necrosis factor- α (TNF- α) in human obesity and insulin resistance. *J. Clin. Invest.* 95:2409-2415. TNF- α has also been identified as an important modulator of transplant rejection. *See* Imagawa, D., Millis, J., Olthoff, K., Derus, L., Chia, D., Sugich, L., Ozawa, M., Dempsey, R., Iwaki, Y., Levy, P., Terasaki, P., Busuttil, R. (1990) "The role of tumor necrosis factor in allograft rejection" *Transplantation*, vol. 50, No. 2, 219-225.

- These observations highlight the importance and desirability of identifying novel strategies and/or novel compounds and classes of compounds that selectively influence the production of TNF- α and/or IL-1. Small molecules that selectively inhibit these cytokines are therefore particularly medicinally and biologically important in, for example, maintaining an active immune system and in treating inflammation based diseases.

Preferred Methods Of Synthesis Of The Present Invention

Certain embodiments of the invention include novel methods of making the compounds having the chemical structure of Formulae (II), (IIA), or (IIB), as well as novel methods of making known analogs of the known the compounds having the chemical structure of Formulae (II), (IIA), or (IIB), for example, the compounds of Formulae (I) and (IA).

The compounds of the present invention, and specifically, the compounds having the chemical structure of Formula (II), (IIA), or (IIB), may be prepared either synthetically or semi-synthetically. If prepared synthetically, commonly available starting materials may be used, including, but not limited to bicyclic compounds having reactive halide moieties. The at-least-three-ringed compounds of the present invention may be synthesized according to various ring closure reactions. Such reactions include, but are not limited to the Diels-Alder reaction, and the Dieckmann Condensation reaction. The Diels-Alder reaction preferably involves the reaction of a diene and an a substituted alkenyl moiety, such that the third ring of the desired compound is formed. The Dieckmann Condensation reaction may be preferably followed by the reduction of the resulting cycloketone moiety. Compounds of the present invention may be purified and isolated, following such synthetic methods and other well-known synthetic methods, by use of procedures, such a chromatography or HPLC, as well known to those skilled in the art.

Alternatively, according to the present invention, the compounds having the chemical structure of Formulae (I) and (IA), and certain specific analogs and derivatives thereof, may be extracted and isolated, at least in the form of a crude extract comprising acanthoic acid, from the root bark of *Acanthopanax koreanum* Nakai. Such an extract may preferably be produced according to the following method:

Approximately one kilogram of dried root bark of *A. koreanum* Nakai is obtained, chipped, and covered with between 1L to 3L, and preferably 2L, of a suitable solvent, most preferably methanol. This mixture is maintained at a temperature ranging from 20° to 60°, and may be maintained at room temperature, for at least 10 hours, and preferably for 12 hours. The mixture is then filtered to remove and retain the filtrate. This procedure is repeated, preferably at least two additional times, and the combined filtrates are concentrated under a reduced pressure to obtain an extract.

Approximately 100 grams of the extract is partitioned with 200 mL to 400 mL, preferably 300 mL, of an aqueous solution, preferably water and 200 mL to 400 mL, preferably 300 mL, of an organic solution, preferably diethyl ether. The organic fraction is separated therefrom and then concentrated under a reduced pressure to obtain a further extract. Said further extract is purified, preferably by column chromatography and even more preferably by use of a silica gel column, using a mixture of

suitable organic solvents, preferably hexane and ethyl acetate as an eluent to obtain isolated acanthoic acid.

This isolated compound of Formulae (I) and (IA) may then be synthetically modified to yield certain compounds of the present invention, specifically the compounds having the chemical structure of Formula (II) or (IIA). For example, ester R_1 analogs of acanthoic acid may be formed according to acid-catalyzed nucleophilic addition of an alkyl alcohol to the carboxylic acid moiety of acanthoic acid. Ether R_1 analogs of acanthoic acid may be formed from either primary alkyl halides or alcohols according to the Williamson Ether synthesis, or via the reduction of a primary alcohol moiety. Alkyl, alkenyl, and alcoholic R_{10} analogs of acanthoic acid may be formed via catalytic hydrogenation of the alkenyl group, or via electrophilic addition of, preferably, HCl or HBr or other suitable alkyl halides. Substitution analogs at the other R positions of acanthoic acid may be formed by displacement reactions involving alkyl halides, provided suitable reactive groups and related protecting groups are employed to encourage the desired reaction. According to these reaction and other well-known synthetic reactions, the production of the full range of the compounds of the present invention, given the description of those compounds provided herein, is within the skill of those of the art.

Fully-synthetic approaches for the preparation of the compounds of the invention, including compounds of general Formulae (I), (IA), (II), (IIA), and (IIB) are described herein. This synthesis includes one or more retrosynthetic analyses of acanthoic acid and its analogs, syntheses of radioactively labeled acanthoic acid and its analogs, syntheses of dimers and conjugates of the compounds of general Formulae (I), (IA), (II), (IIA), and (IIB). Those of skill in the art will also appreciate that these approaches are also fully applicable to the preparation of kauranoic acid and its analogs.

The Compound of Formula (I) and Its Naturally-Occurring Analogs

The root bark of *Acanthopanax koreanum* Nakai (Araliaceae), which is found indigenously in Cheju Island, The Republic of Korea, has been used traditionally as a tonic and sedative, as well as a remedy for the treatment of rheumatism and diabetes. During their investigation of this folk medicine, Chung and coworkers identified from its pharmacologically active extracts two novel tricyclic diterpenes: acanthoic acid (Compound 1) and its methyl ester (Compound 2), as depicted in Figure 1. See Kim, Y. H.; Chung, B. S.; Sankawa, U. "Pimaradiene diterpenes from *Acanthopanax Koreanum*". *J. Nat. Prod.* 1988, 51, 1080-1083. Acanthoic acid is a pimarane (3). However, in sharp contrast to the other members of the pimaranes family, 1 is distinguished by an unusual stereochemical relationship between the C8 and C10 centers that provides a unique mode of connectivity of the BC ring system.

Prior to this invention, no complete chemical synthesis existed for production of the chemical having the structure of Formula (I) or its analogs. Importantly, the chemical structure of Formula (I), 1,

(Figure 1) possesses a biological profile as an anti-inflammatory agent. More specifically, *in vitro* studies with activated (inflamed) monocytes/macrophages revealed that treatment with 1 (approximately 0.1 to approximately 1.0 microgram/ml for 48 hours) leads to an approximately 90% inhibition of the TNF- α and IL-1 production. This inhibition was concentration dependent and cytokine-specific, since under the same conditions the production of IL-6 or IFN- γ (interferon-gamma) were not affected. The *in vivo* effects of acanthoic acid were evaluated in mice suffering from silicosis (chronic lung inflammation) and cirrhosis (liver inflammation and hepatic fibrosis). Histologic analysis revealed that treatment with compound 1 led to a substantial reduction of fibrotic granulomas and a remarkable recovery of the cirrhotic liver cells. These dramatic results can be attributed, at least partially, to inhibition of pro-inflammatory cytokines, such as TNF- α and IL-1, mediated by 1. Compound 1 also shows very little toxicity in mice and only upon orally administering a high concentration (LD $>$ 300 mg/100 g of body weight). See Kang, H.-S.; Kim, Y.-H.; Lee, C.-S.; Lee, J.-J.; Choi, I.; Pyun, K.-H., *Cellular Immunol.* 1996, 170, 212-221. Kang, H.-S.; Song, H. K.; Lee, J.-J.; Pyun, K.-H.; Choi, I., *Mediators Inflamm.* 1998, 7, 257-259.

The chemical structure of Formula (I) thus has potent anti-inflammatory and anti-fibrotic effects and reduces the expression of TNF- α and IL-1. Acanthoic acid is thus used as a chemical prototype for the development of the novel compounds of the invention.

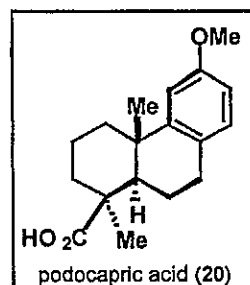
Retrosynthetic Analyses of The Compounds of Formulae (I), (II) and (IIB)

The compounds of Formulae (I), (II) and (IIB), and preferably the compound of Formula (I) and compounds of Formulae (IIB) designated TTL1, TTL2, TTL3, and TTL4 herein, may be synthesized according to an aspect of the invention. The bond disconnections of the compounds of Formulae (I) are shown in Figure 2. The novel structural arrangement of the BC rings and the presence of the quaternary C13 center constitute an unusual motif and lead to a novel strategy that is one aspect of the invention. This motif is fixed, in one step, into the desired stereochemistry by employing a Diels-Alder methodology. A diene, for example, 14, and a dienophile, such as 15 (Y: oxazolidinone-based auxiliary), were identified as the appropriate starting materials for an *endo* selective Diels-Alder reaction. To further ensure the desired regiochemical outcome of this cycloaddition, diene 14 was functionalized transiently with a heteroatom (for example, X= OTBS or SPh), which will be subsequently removed from the product 13. The generally observed *endo* preference of this reaction was used to predict the stereochemical relationship between the C12 and C13 centers as shown in product 13, while the diastereofacial selectivity of the process will be controlled either by a chiral auxiliary at the carbonyl center of the dienophile or by using a chiral catalyst. See Xiang, A. X.; Watson, D. A.; Ling, T.; Theodorakis, E. A. "Total Synthesis of Clerocidin via a Novel, Enantioselective Homoallenylboration Methodology". *J. Org. Chem.* 1998, 63, 6774-6775.

Diene 14 may be formed by a palladium (0) catalyzed construction of the C8-C11 bond, revealing ketone 16 as its synthetic progenitor. This ketone was formed from the known Wieland-Miescher ketone (17), which in turn was readily available by condensation of methyl vinyl ketone (19) with 2-methyl 1,3-cyclohexane dione (18) (Figure 2).

5 In one aspect of the invention, it is recognized that the functionalities and relative stereochemistry of the AB ring system of acanthoic acid (1) are akin to those in the structure of podocarpic acid (20). See "The total synthesis of natural products." ApSimon, Ed.; John Wiley & Sons, Inc., 1973, Volume 8, pages 1-243. Among the several synthetic strategies toward 20, highlights of the ones may be relevant to our proposed synthesis of 1 are shown in Figure 5. According to the
10 invention, these approaches allowed the prediction of the stereochemical outcome of the synthesis of The compounds of Formulae (I), (II) and the contrary stereochemical of the compounds of Formulae (IIB), and the compounds of Formulae (IIB) that are designated TTL1, TTL2, TTL3, and TTL4 herein.
Complete syntheses of the Compounds of Formulae (I), (II) and (IIB)

The initial step of the synthesis of acanthoic acid (1), and of all compounds of Formulae (I), (II)
15 and (IIB), involves the reaction of a Wieland-Miescher ketone (17). This compound was readily available from compounds 18 and 19 as a single enantiomer by a Michael addition/Robinson annulation sequence using catalytic amounts of (R)-proline. Selective protection of the more basic C9 carbonyl group of 17, followed by a reductive alkylation of enone 34 with methyl cyanoformate gave rise to ketoseter 36. Transformation of 36 to 39 was based on previous
20 studies, see Welch, S. C.; Hagan, C. P. "A new stereoselective method for developing ring A of podocarpic acid compounds" *Synthetic Commun.* 1972, 2, 221-225, as depicted in Figure 3. Reduction of the ester functionality of 39, followed by silylation of the resulting alcohol and acid-catalyzed deprotection of the ketal unit then afforded
25 ketone 40. Conversion of 40 to the desired diene 42 was accomplished by a two step sequence involving transformation of 40 to its corresponding enol triflate derivative, followed by palladium catalyzed coupling with vinyl stannane 41. See Farine, V.; Hauck, S. I.; Firestone, R. A. "Synthesis of cepheids bearing olefinic sulfoxide side chains as potential b-lactamase inhibitors" *Bioorg. & Medicinal Chem. Lett.* 1996, 6, 1613-1618.
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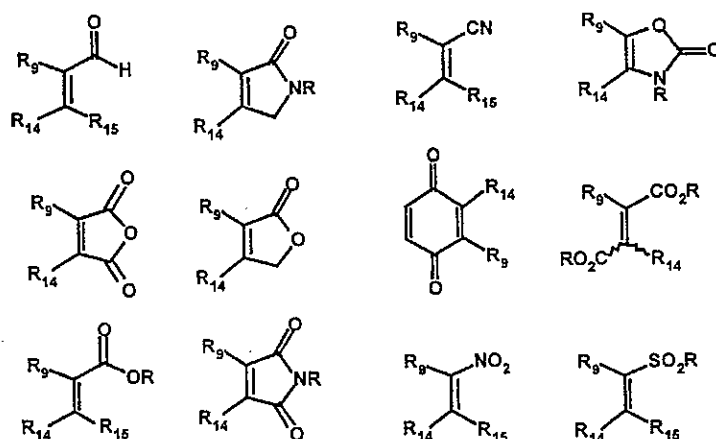


The steps that were used in the completion of the synthesis of acanthoic acid (1), and are used in the completion of the syntheses of compounds of Formulae (I), (II) and (IIB) are depicted in Figure 5, as Scheme 2. A Diels-Alder cycloaddition between diene 42 and dienophile 43, followed by reductive desulfurization with Raney Ni produces the tricyclic system 44 with the desired

stereochemistry. Transformation of 44 to the Weinreb amide, followed by reduction with DIBALH generated aldehyde 45, which upon Wittig reaction gave rise to olefin 46. Fluoride-induced desilylation of 46, followed by a two steps oxidation of the resulting alcohol to the carboxylic acid produced acanthoic acid (1), and may be used to produce the compounds of Formulae (I), (II) and (IIB)

5 by appropriate substitution of the intermediates.

One important step to the synthesis of compounds of Formulae (I) and (IA), and the compounds of Formulae (II), (IIA) and (IIB), is the Diels-Alder reaction. This reaction, and the use and selection of one or more appropriately substituted dienes and/or dienophiles permits the selective synthesis of compounds of Formula (II) or the selective synthesis of compounds of Formula (IIB). For example, the following preferred dienophiles may be used in place of the dienophiles, for example, compound 43 and pimarane (103), as depicted herein in, for example, Figures 5, 7, 8, 21, and 23, as Reaction Schemes 2, 3, 4, 5, and 6, to selectively yield compounds of Formulae (II) and (IIB). Exemplary dienophiles include those of Formulae (III):



(III)

wherein the numbered R-groups (R_9 , R_{14} , and R_{15}) are as designated above for the compounds of Formula (IIB), and the unnumbered R groups may be any of R_1 through R_{15} as designated above for the compounds of Formula (IIB).

Furthermore, the electronic conformation of the diene, for example compound (42) and compound (112), as depicted herein in, for example, Figures 5, 7, 8, 21, and 23, as Reaction Schemes 2, 3, 4, 5, and 6, respectively, may be altered by the covalent linkage of electron-donating or electron-withdrawing group, for example, pHS, to the diene. As exemplified herein, such a covalently linked electron-donating or electron-withdrawing group effects the orientation of the incoming dieneophile.

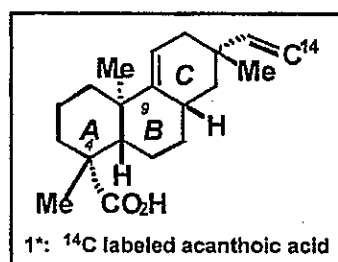
Thus, according to one aspect of the invention, the chiral nature of diene **42** allows it to be used to induce asymmetry during the cycloaddition. Examination of a minimized model of **42** indicates that the angular methyl at C10 influences the facial selectivity of the reaction and allow more efficient approach of the dienophile from the top face of the diene. This approach produced the adduct that leads to compounds of Formulae (IIB). This approach also allowed for the development of a catalytic asymmetric variant of the Diels Alder reaction. The benefits of using chiral catalysts, as opposed to chiral auxiliaries, are obvious and well documented in the recent literature.

One preferred embodiment of the invention is the use of catalyst **49**, that was developed and applied by Corey toward an improved asymmetric synthesis of cassiol (Scheme 3). *See* Corey, E. J.; Imai, N.; Zhang, H.-Y. *J. Am. Chem. Soc.* 1994, *116*, 3611. Compound **49** was shown to allow Diels-Alder cycloaddition of an electronically rich diene **47** with methacrolein (**48**) and produce exclusively the *endo* adduct in excellent yield and enantiomeric excess (83% yield, 97% ee).

Application of the above methodology to our synthesis is depicted in Figure 8, as Scheme 4. Use of catalyst **49** provided additional versatility and significantly shorten the total amount of steps required for completion of the total synthesis of **1**.

Synthesis of Radiolabeled Compounds of Formula (I)

A radiolabeled sample of a compound of Formulae (I), (II), (IIA) or (IIB) may be synthesized and is useful in pharmacological and pharmacokinetic studies. For example, a C14-labeled methylene carbon is incorporated on the compound of Formulae (I) using aldehyde **52** as a starting material (as depicted in Figure 4, Scheme 4). The C14-labeled yield, required for the Wittig chemistry, is prepared in two steps from C14-labeled iodomethane and triphenyl-phosphine, followed by treatment with a base, such as NaHMDS. Base-induced deprotection of the methylester produces radiolabeled a compound of Formulae (I), (II), (IIA) or (IIB).



Objectives of the Syntheses of the Compounds of Formula (II), (IIA) and (IIB)

One aspect of the invention is the identification of novel anti-inflammatory drugs having the structure of the compounds of Formula (II), (IIA) and (IIB). Biological screening of synthetic intermediates and rationally designed compounds of Formula (II) provide information and guide the design requirements.

The design and synthesis of analogs of the compounds of Formula (II) is based on the following objectives: (a) defining the minimum structural and functional requirements the compounds of Formula (II) that are responsible for the TNF- α and IL-1 modulating activity (minimum pharmacophore); (b) improving the TNF- α and IL-1 modulating activity of the compounds of Formula (II) by altering the structure, particularly the R-groups of the minimum pharmacophore (for example, SAR studies and molecular recognition experiments); (c) examining the mode of action of the compounds of Formula (II) by photoaffinity labeling studies; (d) modifying and improving the solubility and membrane permeability of the compounds of Formula (II); (e) synthesizing and study dimers or conjugates of the compounds of Formula (II); selective delivery units and (f) redesigning and refining the target structure by evaluating the obtained biological data.

Of particular significance to the rational design of novel the compounds of Formulae (II), (IIA) and (IIB) are the recent reports that modification of the A and C rings of oleanolic acid (53), as depicted in Figure 9, lead to enhanced antiproliferative and antiinflammatory activity. See Honda, T.; Rounds, B. V.; Gribble, G. W.; Suh, N.; Wang, Y.; Sporn, M. B. "Design and synthesis of 2-cyano-3,12-dioxolean-1,9-dien-28-oic acid, a novel and highly active inhibitor of nitric oxide production in mouse macrophages" *Biorg. & Medic. Chem. Lett.* 1998, 8, 2711-2714. Suh, N. et al "A novel synthetic oleanane triterpenoid, 2-cyano-3,12-dioxolean-1,9-dien-28-oic acid, with potent differentiating, antiproliferative and anti-inflammatory activity" *Cancer Res.* 1999, 59, 336-341. More specifically, SAR studies with commercially available 53 and semisynthetic derivatives thereof have led to the recognition that that: (a) attachment of electron-withdrawing groups, such as nitrile, at the C2 position increases the biological potency of 53 (Figure 9); (b) an α,β unsaturated ketone functionality at the C ring is a strong enhancer of potency. The combination of these observations lead to the semisynthesis of a designed triterpenoid 54 (Figure 9), shown to be 500-fold more active than any other known triterpenoid in suppressing the inflammatory enzymes iNOS (inducible nitric oxide synthase) and COX-2 (cyclooxygenase-2) (Figure 9).

Synthesis of the Compounds of Formulae (II), (IIA) and (IIB)

The thirteen-step synthesis of the compounds of Formulae (II), (IIA) and (IIB) (as shown in Figures 4 and 8, Schemes 1 and 4, respectively) is efficient and as such, it allows the preparation of a variety of analogs useful in SAR studies. The biological significance of the unusual tricyclic scaffold

of the compounds of Formulae (II), (IIA) and (IIB) (the C8 epimer is constructed using the appropriate Diels-Alder catalyst). The sites that are easily altered *via* the synthetic approach of the invention, or by standard modifications of our synthetic intermediates are shown in the Figure 10, and representative examples of the compounds of Formula (II) are shown in Figure 11.

5 The desired chemical scaffold of the compounds of Formula (II), (IIA) and (IIB) may also be incorporated into solid support such as, for example, a Wang resin. This permits the facile construction of combinatorial libraries of the compounds of Formula (II), (IIA) and (IIB). Furthermore, according to the invention, preferred TNF- α and IL-1 modulators may be more rapidly identified and screen that currently possible.

10 Photoaffinity labeling studies. The backbone of the compounds of Formula (II), (IIA) and (IIB) is also preferably labeled with a reactive cross-linker, that is useful in photoaffinity labeling studies. These studies assist in the identification of the *in vivo* target of the compounds of Formula (II), (IIA) and (IIB) and provide fundamental insights into the mode of action of acanthoic acid and on the activation of TNF- α . The C19 carboxylic acid or the C15 aldehyde (precursor of 1) are useful in cross-
15 linking experiments with the appropriate photosensitive reagents (see 60 and 61, Figure 12).

Synthesis of dimers and conjugates of the compounds of Formula (II), (IIA) and (IIB)

Dimeric forms the compounds of Formula (II), (IIA) and (IIB), such as for example 62 ($n=1$), have been isolated from natural sources and, furthermore, the dexamethasone-acanthoic acid conjugate 63 provides biologically interesting results toward a drug targeting a steroid receptor with potential
20 implications in cancer research.. See Chamy, M. C.; Piovano, M.; Garbarino, J. A.; Miranda, C.; Vicente, G. *Phytochemistry* 1990, 9, 2943-2946. While no biological studies of this class of compounds has been performed, according to the invention, dimeric analogs of Formula (II), (IIA) and (IIB) are evaluated. Synthetic acanthoic acid or bioactive analogs of 1 are used as monomeric partners and their coupling is performed using standard techniques, included those described herein.

25 Experimental Techniques

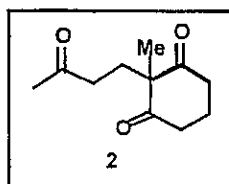
All reactions were carried out under an argon atmosphere in dry, freshly distilled solvents under anhydrous conditions, unless otherwise noted. Tetrahydrofuran (THF) and diethyl ether (Et₂O) were distilled from sodium/benzophenone; dichloromethane (CH₂Cl₂), hexamethyl phosphoramide (HMPA), and toluene from calcium hydride; and dimethyl formamide (DMF) from calcium chloride.

30 Yields refer to chromatographically and spectroscopically (¹H NMR) homogeneous materials, unless otherwise stated. Reagents were purchased at highest commercial quality and used without further purification, unless otherwise stated. Reactions were monitored by thin-layer chromatography carried out on 0.25 mm E. Merck silica gel plates (60F-254) using UV light as visualizing agent and 7% ethanolic phosphomolybdic acid, or *p*-anisaldehyde solution and heat as developing agents. E. Merck

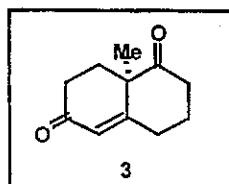
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silica gel (60, particle size 0.040-0.063 mm) was used for flash chromatography. Preparative thin-layer chromatography separations were carried out on 0.25 or 0.50 mm E. Merck silica plates (60F-254). NMR spectra were recorded on a Varian 400 and/or 500 Mhz instruments and calibrated using a residual undeuterated solvent as an internal reference. The following abbreviations were used to explain the multiplicities: s = singlet; d = doublet; t = triplet; q = quartet; m = multiplet, b = broad. IR spectra were recorded on a Nicolet Avatar 320 FT-IR spectrometer. Optical rotations were recorded on a Perkin Elmer 241 polarimeter. High resolution mass spectra (HRMS) were recorded on a VG 7070 HS mass spectrometer under chemical ionization (CI) conditions or on a VG ZAB-ZSE mass spectrometer under fast atom bombardment (FAB) conditions.



Triketone 2. A solution of diketone 1 (50 g, 0.40 mol) in ethyl acetate (500 ml) was treated with triethylamine (72 ml, 0.52 mol) and methyl vinyl ketone (36 ml, 0.44 mol). The reaction mixture was refluxed at 70 °C for 10 h and then cooled to 25 °C. The solvent was removed under pressure and the resulting crude material was chromatographed directly (10-40% ether in hexanes) to yield triketone 2 (61 g, 0.31 mol, 78%). 2: colorless oil; R_f = 0.25 (silica, 50% ether in hexanes); ^1H NMR (400 MHz, CDCl_3) δ 2.75-2.59 (m, 4H), 2.34 (t, 2H, J = 7.2 Hz), 2.10 (s, 3H), 2.07-2.05 (m, 3H), 1.98-1.94 (m, 1H), 1.24 (s, 3H).

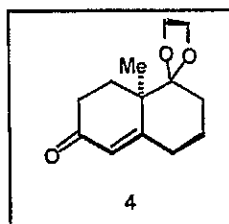


Wieland-Miescher ketone (3) A solution of triketone 2 (61 g, 0.31 mol) in dimethyl sulfoxide (400 ml) was treated with finely ground D-proline (1.7 g, 0.01 mol). The solution was stirred at 25 °C for 4 days and then stirred at 40 °C for 1 more day. The resulting purple colored solution was cooled to 25

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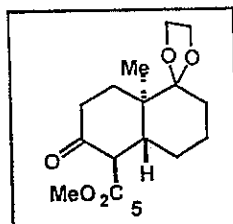
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C, diluted with water (300 ml) and brine (100 ml), and poured into a separatory funnel. The mixture was extracted with ethyl ether (3 x 800 ml). The organic layers were concentrated (without drying) and subjected to chromatography (10-40% ether in hexanes) to give 59 g of a crude reddish-violet oil. The material was again subjected to chromatography (10-40% ether in hexanes) and concentrated to yield 57 g of a yellow oil. The oil was dissolved in ethyl ether (400 ml) and kept at 4 °C for 30 min, after which time a layer of hexanes (100 ml) was added on top of the ether. The two-layered solution was seeded with a few crystals and placed into a freezer (-28 °C) overnight. The resulting crystals were collected by filtration, rinsed with ice-cold hexanes (2 x 100 ml), and dried under pressure. Concentration of the mother liquor afforded another crop, and combining the crystals afforded the Wieland-Miescher ketone (3) (43 g, 0.24 mol, 78%). 3: tan crystals: R_f = 0.25 (silica, 50% ether in hexanes); $[\alpha]^{25}_D$: -80.0 (c = 1, C_6H_6); 1H NMR (400 MHz, $CDCl_3$) δ 5.85 (s, 1H), 2.72-2.66 (m, 2H), 2.51-2.42 (m, 4H), 2.14-2.10 (m, 3H), 1.71-1.68 (m, 1H), 1.44 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 210.7, 198.0, 165.6, 125.7, 50.6, 37.7, 33.7, 31.8, 29.7, 23.4, 23.0.



Acetal 4. A solution of ketone 3 (43 g, 0.24 mol) in benzene (700 ml) was treated with p-toluenesulfonic acid (4.6 g, 0.024 mol) and ethylene glycol (15 ml, 0.27 mol). The reaction was refluxed with a Dean-Stark apparatus and condenser at 120 °C. Once water stopped collecting in the Dean-Stark apparatus, the reaction was complete (approx. 4 h). Leaving the reaction for longer periods of time tended to darken the reaction mixture and lower the overall yield. The reaction was cooled to 25 °C, quenched with triethylamine (5 ml, 0.036 mol), and poured into a separatory funnel containing water (300 ml) and saturated sodium bicarbonate (200 ml). The resulting mixture was then extracted with ether (3 x 800 ml). The organic layers were combined, dried over $MgSO_4$, concentrated, and subjected to chromatography (10-40% ether in hexanes) to afford acetal 4 (48 g, 0.22 mol, 90%). 4: yellow oil; R_f = 0.30 (silica, 50% ether in hexanes); $[\alpha]^{25}_D$: -77 (c = 1, C_6H_6); IR (film) ν_{max} 2943, 2790, 1667, 1450, 1325, 1250; 1H NMR (400 MHz, $CDCl_3$) δ 5.80 (s, 1H), 3.98-3.93 (m, 4H), 2.43-

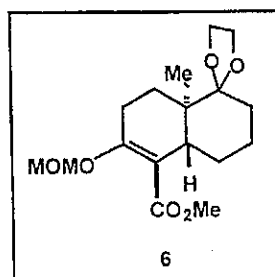
2.35 (m, 3H), 2.34-2.20 (m, 3H), 1.94-1.82 (m, 1H), 1.78-1.60 (m, 3H), 1.34 (s, 3H); ^{13}C NMR (100 MHz, CDCl_3) δ 198.9, 167.5, 125.5, 112.2, 65.4, 65.1, 45.1, 34.0, 31.5, 30.1, 26.9, 21.8, 20.6.



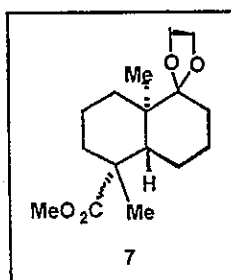
- 5
- 10 **Ketoester 5.** A solution of lithium (0.72 g, 0.10 mol) in liquid ammonia (400 ml) at -78 °C was treated dropwise with a solution of acetal 4 (10 g, 0.045 mol) and *tert*-butyl alcohol (3.7 ml, 0.045 mol) in ether (40 ml). The resulting blue mixture was allowed to warm and stir at reflux (-33 °C) for 15 min and then cooled to -78 °C again. Sufficient isoprene (approx. 8 ml) was added dropwise to discharge the residual blue color of the reaction mixture. The reaction was then warmed in a water bath (50 °C)
- 15 and the ammonia quickly evaporated under a stream of dry nitrogen. The remaining ether was removed under pressure to leave a white foam. After a further 5 min under high vacuum, the nitrogen atmosphere was restored, and the lithium enolate was suspended in dry ether (150 ml) and cooled to -78 °C. Methyl cyanoformate (4.0 ml, 0.050 mol) was then added and the reaction stirred for 40 min at -78 °C. The reaction was warmed to 0 °C and stirred for 1 h more. Water (300 ml) and ether (200 ml) were
- 20 added and the mixture poured into a separatory funnel containing saturated sodium chloride (100 ml). After separating the organic layer, the aqueous phase was extracted with ether (2 x 400 ml). The combined organic layers were dried over MgSO_4 , concentrated, and subjected to chromatography (10-40% ether in hexanes) to afford ketoester 5 (7.0 g, 0.025 mol, 55%). 5: white powdery precipitate; R_f = 0.40 (silica, 50% ether in hexanes); $[\alpha]_D^{25}$: -2.9 (c = 1, C_6H_6); IR (film) ν_{max} 2943, 1746, 1700; ^1H
- 25 NMR (400 MHz, CDCl_3) δ 4.00-3.96 (m, 2H), 3.95-3.86 (m, 2H), 3.74 (s, 3H), 3.23 (d, 1H, J = 13.2 Hz), 2.50-2.42 (m, 3H), 2.05-1.92 (m, 1H), 1.79-1.50 (m, 5H), 1.32-1.28 (m, 2H), 1.21 (s, 3H); ^{13}C NMR (100 MHz, CDCl_3) δ 205.4, 170.0, 111.9, 65.2, 65.1, 59.9, 52.0, 43.7, 41.6, 37.5, 30.3, 29.8, 26.2, 22.5, 14.0; HRMS, calcd for $\text{C}_{15}\text{H}_{22}\text{O}_5$ ($\text{M}+\text{Na}^+$) 305.1359, found 305.1354.

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Ester 6. A solution of ketoester 5 (7.0 g, 0.025 mol) in HMPA (50 ml) was treated with sodium hydride (0.71 g, 0.030 mol). After stirring for 3 h at 25 °C, the resulting yellow-brown reaction mixture was quenched with chloromethyl methyl ether (2.3 ml, 0.030 mol) and the reaction allowed to stir an additional 2 h at 25 °C. The resulting white-yellow mixture was then poured into a separatory funnel containing ice-water (100 ml), saturated sodium bicarbonate (50 ml), and ether (200 ml). After the layers were separated, the aqueous layer was extracted with ether (3 x 200 ml). The combined ethereal extracts were dried over MgSO₄, concentrated, and subjected to chromatography (silica, 10-40% ether in hexanes) to yield ester 6 (7.7 g, 0.024 mol, 95%). 6: yellow oil; R_f 0.45 (silica, 50% ether in hexanes); $[\alpha]^{25}_D$: +26.3 ($c=1$, C₆H₆); IR (film) ν_{max} 2951, 1728, 1690, 1430, 1170; ¹H NMR (400 MHz, CDCl₃) δ 4.89 (dd, 2H, $J=22.8, 6.4$ Hz), 3.93-3.91 (m, 2H), 3.90-3.84 (m, 2H), 3.69 (s, 3H), 3.40 (s, 3H), 2.72-2.68 (m, 1H), 2.24 (bs, 2H), 1.80-1.42 (m, 4H), 1.37-1.15 (m, 2H), 0.960 (s, 3H), 0.95-0.80 (m, 2H); ¹³C NMR (100 MHz, CDCl₃) δ 167.8, 150.5, 115.8, 112.1, 93.0, 65.2, 65.1, 56.3, 51.3, 40.7, 40.3, 30.3, 26.4, 23.6, 22.9, 22.3, 13.9; HRMS, calcd for C₁₇H₂₆O₆ (M+Na⁺) 349.1622, found 349.1621.

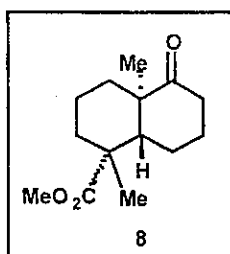


Acetal 7. A solution of lithium (1.1 g, 0.17 mol) in liquid ammonia (400 ml) at -78 °C was treated dropwise with a solution of ester 6 (7.7 g, 0.024 mol) in 1,2-DME (30 ml). The blue reaction mixture

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was allowed to warm and stir at reflux (-33 °C) for 20 min. The reaction mixture was then cooled to -78 °C again and rapidly quenched with excess iodomethane (15 ml, 0.24 mol). The resulting white slurry was allowed to stir at reflux (-33 °C) for 1 h, after which time the reaction was warmed in a water bath (50 °C) with stirring for 1 h, allowing the ammonia to evaporate. The reaction mixture was quenched with water (100 ml), sodium bicarbonate (100 ml), and ether (200 ml) and poured into a separatory funnel. After the layers were separated, the aqueous layer was extracted with ether (3 x 200 ml). The combined ethereal extracts were dried over MgSO₄, concentrated, and subjected to chromatography (silica, 10-30% ether in hexanes) to yield acetal 7 (4.1 g, 0.014 mol, 61%). 7: semi-crystalline yellow oil; R_f 0.80 (silica, 50% ether in hexanes); $[\alpha]_D^{25}$: +16.9 (c=10, C₆H₆); IR (film) $\nu_{\max}$ 2934, 1728, 1466, 1379, 1283, 1125, 942; ¹H NMR (400 MHz, CDCl₃) δ 3.95-3.80 (m, 4H), 3.64 (s, 3H), 2.17-2.15 (m, 1H), 1.84-1.37 (m, 11H), 1.16 (s, 3H), 1.05-1.00 (m, 1H), 0.87 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 177.7, 112.9, 65.2, 64.9, 51.2, 44.0, 43.7, 38.1, 30.7, 30.3, 28.8, 23.4, 19.1, 14.7; HRMS, calcd for C₁₆H₂₆O₄ (M+H⁺) 283.1904, found 283.1904.

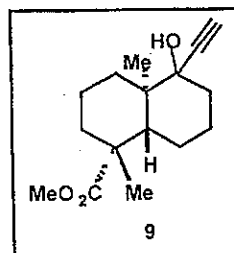


Ketone 8. A solution of acetal 7 (4.1 g, 0.014 mol) in THF (50 ml) was treated with 1M HCl dropwise (approx. 15 ml) at 25 °C with stirring. The reaction was monitored by thin layer chromatography and neutralized with sodium bicarbonate (30 ml) once the starting material disappeared. The resulting mixture was poured into a separatory funnel containing water (100 ml) and ether (100 ml). After the layers were separated, the aqueous layer was extracted with ether (3 x 100 ml). The combined ethereal extracts were dried over MgSO₄, concentrated, and subjected to chromatography (silica, 10-20% ether in hexanes) to yield ketone 8 (3.3 g, 0.014 mol, 95%). 8: white crystals; R_f 0.70 (silica, 50% ether in hexanes); $[\alpha]_D^{25}$: +3.5 (c= 1.0, C₆H₆); IR (film) $\nu_{\max}$ 2943, 1728, 1449, 1239, 1143, 1095, 985; ¹H NMR (400 MHz, CDCl₃) δ 3.62 (s, 3H), 2.55-2.45 (m, 1H), 2.92-1.95 (m, 5H), 1.8-1.6 (m, 2H), 1.50-1.30 (m, 4H), 1.14 (s, 3H), 0.98-0.96 (m, 1H), 0.90 (s, 3H); ¹³C NMR (100 MHz, CDCl₃) δ

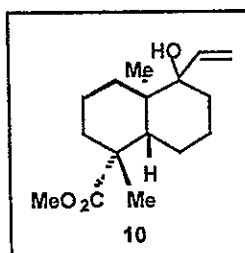
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214.8, 177.0, 54.4, 51.3, 49.3, 44.2, 37.9, 37.7, 33.1, 28.6, 26.4, 22.8, 18.8, 17.0; HRMS, calcd for $C_{14}H_{22}O_3$ ($M+Na^+$) 261.1461, found 261.1482.



Alkyne 9. A solution of ketone 8 (2.0 g, 8.3 mmol) in ether (50 ml) was treated with lithium acetylide (0.40 g, 13 mmol). The reaction was stirred at 25 C for 1 h and then quenched with sodium bicarbonate (20 ml) and water (30 ml). The mixture was poured into a separatory funnel and the layers were separated. The aqueous layer was extracted with ether (3 x 50 ml). The organic layers were combined, dried with $MgSO_4$, concentrated, and subjected to chromatography (silica, 10-30% ether in hexanes) to afford alkyne 9 (2.0 g, 7.6 mmol, 90%). 9: white solid; R_f 0.65 (silica, 50% ether in hexanes); 1H NMR (400 MHz, $CDCl_3$) δ 3.64 (s, 3H), 2.56 (s, 1H), 2.18-2.10 (m, 1H), 1.92-1.40 (m, 12H), 1.18 (s, 3H), 1.17-1.01 (m, 1H), 0.81 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) 177.6, 86.8, 76.5, 75.0, 51.2, 50.5, 43.9, 52.5, 37.9, 35.3, 33.4, 28.8, 23.5, 22.5, 19.1, 11.5; HRMS, calcd for $C_{16}H_{24}O_3$ ($M+H^+-H_2O$) 247.1693, found 247.1697.

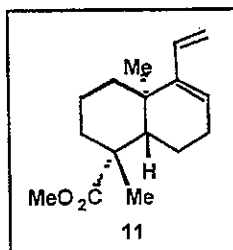


Alkene 10. A solution of alkyne 9 (0.50 g, 1.9 mmol) in 1,4 dioxane (20 ml) and pyridine (2 ml) was treated with Lindlar's catalyst (100 mg). The mixture was hydrogenated under pressure (30 lbs/in²) for 7 min. The reaction mixture was then diluted with ether (10 ml), filtered through a pad of celite, and

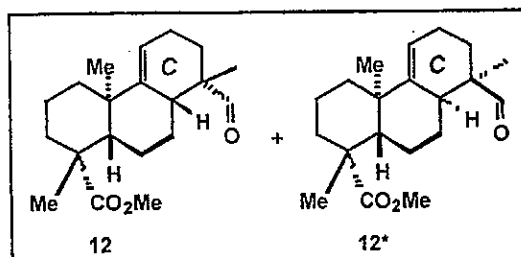
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washed with ether (2 x 50 ml). The solvent was evaporated under reduced pressure to afford alkene 10 (0.48 g, 1.8 mmol, 95%). 10: colorless oil; ^1H NMR (400 MHz, CDCl_3) δ 6.58 (dd, 1H), 5.39 (d, 1H), 5.14 (d, 1H), 3.64 (s, 3H), 2.20-2.11 (m, 2H), 1.93-1.65 (m, 4H), 1.61 (s, 2H), 1.52-1.25 (m, 4H), 1.19 (s, 3H), 1.17-0.90 (m, 2H), 0.89 (s, 3H).



Diene 11. A solution of alkene 10 (0.48 g, 1.8 mmol) in benzene (80 ml) and THF (20 ml) was treated with boron trifluoride etherate (1 ml, 7.9 mmol), and the reaction mixture was refluxed at 100 C for 5 h. After cooling, the reaction was quenched with 1N NaOH (1 ml, 26 mmol) and the mixture was poured into a separatory funnel containing water (100 ml) and ether (100 ml). After separating the layers, the aqueous layer was extracted with ether (3 x 100 ml). The organic layers were combined, dried with MgSO_4 , concentrated, and subjected to chromatography (silica, 5% ether in hexanes) to afford diene 11 (0.42 g, 1.7 mmol, 95%). 11: colorless oil; R_f = 0.95 (silica, 50% ether in hexanes); ^1H NMR (400 MHz, CDCl_3) δ 6.26-6.23 (dd, 1H), 5.70 (s, 1H), 5.253 (d, 1H, J = 19.2 Hz), 4.91 (d, 1H, J = 12.8 Hz), 3.64 (s, 3H), 2.22-2.12 (m, 2H), 2.10-1.94 (m, 2H), 1.92-1.67 (m, 3H), 1.60-1.44 (m, 3H), 1.378 (d, 1H, J = 13.6), 1.21 (s, 1H), 1.19-1.00 (m, 2H), 0.86 (s, 3H); ^{13}C NMR (100 MHz, CDCl_3) δ 177.7, 146.7, 136.1, 121.9, 113.3, 53.0, 51.2, 43.9, 38.0, 37.9, 37.4, 28.5, 27.8, 20.5, 19.5, 18.3.

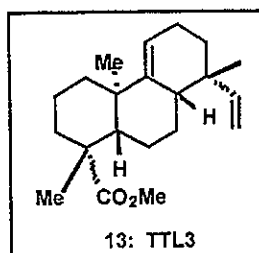


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Aldehyde 12. A solution of methacrolein (0.5 ml, 5.2 mmol) and diene **11** (0.1 g, 0.40 mmol) was stirred for 8 h at 25 °C under neat conditions. The excess methacrolein was then removed under reduced pressure. The crude product was subjected to chromatography (silica, 10-20% ether in hexanes) to afford aldehydes **12** and **12*** (0.13 g, 0.40 mmol, 100%) as a mixture of diastereomers (3:1-4:1 ratio at C13). **12** and **12***: colorless oil: R_f 0.55 (silica, 25% ether in hexanes); **12**: IR (film) $\nu_{\max}$ 3441, 2936, 1726, 1451, 1233, 1152; ^1H NMR (400 MHz, CDCl_3) δ 9.70 (s, 1H), 5.58 (m, 1H), 3.62 (s, 3H), 2.38-2.25 (m, 1H), 2.21-2.18 (m, 1H), 2.17-1.98 (m, 4H), 1.96-1.62 (m, 6H), 1.61-1.58 (m, 1H), 1.57-1.43 (m, 2H), 1.40-1.23 (m, 1H), 1.17 (s, 3H), 1.04 (s, 3H), 0.92 (s, 3H); ^{13}C (100 MHz, CDCl_3) δ 207.6, 177.7, 148.3, 188.6, 51.3, 47.8, 47.0, 44.2, 41.2, 39.3, 38.8, 38.1, 29.5, 28.4, 22.9, 22.5, 21.8, 20.6, 20.5, 19.7; **12***: $[\alpha]_{25}^D$: +36.8 (c = 0.7, C_6H_6); IR (film) $\nu_{\max}$ 3441, 2936, 1726, 1451, 1233, 1152; ^1H NMR (400 MHz, CDCl_3) δ 9.64 (s, 1H), 5.42 (m, 1H), 3.66 (s, 3H), 2.29-2.10 (m, 4H), 2.09-1.84 (m, 4H), 1.81-1.77 (m, 2H), 1.75-1.63 (m, 2H), 1.62-1.58 (m, 2H), 1.57-1.45 (m, 1H), 1.43 (s, 1H), 1.13 (s, 3H), 1.03 (s, 3H), 0.87 (s, 3H); ^{13}C NMR (100 MHz, CDCl_3) δ 207.3, 177.5, 147.4, 114.6, 55.8, 51.3, 47.3, 44.5, 40.7, 40.4, 38.4, 37.5, 31.5, 28.6, 25.0, 24.2, 21.9, 19.9, 19.6, 18.7.

The preferred way to purify the diastereomeric aldehydes is to reduce them with sodium borohydride in MeOH and separate the alcohols. The major compound (top diastereomer) can then be oxidized to the desired aldehyde **12** upon treatment with Dess-Martin periodinane.

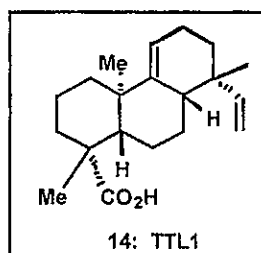


Alkene 13 (TTL3). A solution of (methyl)-triphenyl-phosphonium bromide (357 mg, 1.0 mmol) in THF (40 ml) was treated with 1M NaHMDS in THF (0.86 ml, 0.86 mmol). The resulting yellow mixture was allowed to stir at 25 °C for 30 min. After this time, a solution of aldehyde **12** (91 mg, 0.29 mmol) in THF (10 ml) was added to the reaction via cannula. The reaction mixture was stirred at 25 °C for 8 hours and then quenched with sodium bicarbonate (30 ml) and water (20 ml). The mixture was poured into a separatory funnel containing ether (50 ml). After separating the layers, the aqueous layer

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was extracted with ether (3 x 50 ml). The organic layers were combined, dried with MgSO_4 , condensed, and subjected to chromatography (silica, 10% ether in hexanes) to afford alkene 13 (84 mg, 0.28 mmol, 97%). 13: colorless oil; $R_f = 0.75$ (silica, 25% ether in hexanes); 13: ^1H NMR (400 MHz, CDCl_3) δ 5.96dd, 1H, $J = 16.8, 11.6$ Hz), 5.50 (m, 1H), 4.98 (m, 2H), 3.62 (s, 3H), 2.20-2.11 (m, 1H), 2.10-1.91 (m, 4H), 1.90-1.70 (m, 4H), 1.69-1.51 (m, 3H), 1.50-1.38 (m, 3H), 1.36-1.24 (m, 1H), 1.17 (s, 3H), 1.04 (s, 3H), 0.90 (s, 3H); ^{13}C NMR (100 MHz, CDCl_3) δ 177.9, 149.1, 143.8, 117.9, 111.7, 51.2, 47.7, 44.4, 41.4, 41.2, 38.9, 38.3, 37.7, 34.8, 30.4, 28.4, 24.8, 23.1, 22.3, 22.2, 20.6, 19.8.



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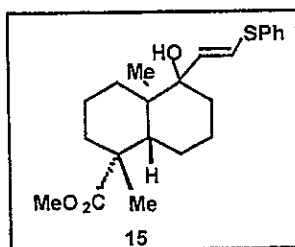
Acid 14 (TTL1). A solution of alkene 13 (84 mg, 0.28 mmol) in dimethyl sulfoxide (20 ml) was treated with LiBr (121 mg, 1.4 mmol). The reaction mixture was refluxed at 180 °C for 2 days. After cooling down, the reaction was diluted with water (30 ml) and extracted with ether (3 x 50 ml). The organic layers were combined, dried with MgSO_4 , concentrated, and subjected to chromatography (silica, 30% ether in hexanes) to afford carboxylic acid 14 (TTL1) (78 mg, 0.26 mmol). 14: white solid; $R_f = 0.30$ (silica, 30% ether in hexanes); ^1H NMR (400 MHz, CDCl_3) δ 5.96 (dd, 1H, $J = 14.4, 9.6$ Hz), 5.52 (m, 1H), 4.98-4.95 (m, 2H), 2.20-1.72 (m, 10H), 1.64-1.58 (m, 3H), 1.57-1.37 (m, 4H), 1.22 (s, 3H), 1.04 (s, 3H), 0.99 (s, 3H); ^{13}C NMR (100 MHz, CDCl_3) δ 182.9, 149.3, 143.9, 118.1, 111.9, 47.5, 44.2, 41.3, 41.2, 38.9, 38.0, 37.6, 34.8, 28.4, 24.7, 23.0, 22.4, 21.9, 20.3, 19.5.

Preparation of $\text{Ph}_3\text{P}=\text{}^{14}\text{CH}_2$.

Triphenylphosphine (0.16 g, 0.61 mmol) was added in a 15 ml reaction flask and dried overnight under vacuum at 25 °C. To this flask was added 2 ml of THF (dried and degassed under vacuum), followed by $^{14}\text{CH}_3\text{I}$ (50 mCi, 53 mCi/mmol, 0.9 mmol) dissolved in 1 ml of THF and the mixture was stirred for 24 hours under argon. Potassium hexamethyldisilylamide (2.5 ml, 1.25 mmol, 0.5 M in toluene) was then added and the reddish-yellow mixture was allowed to stir for 3 h at 25 °C.

Wittig reaction with $\text{Ph}_3\text{P}=\text{}^{14}\text{CH}_2$.

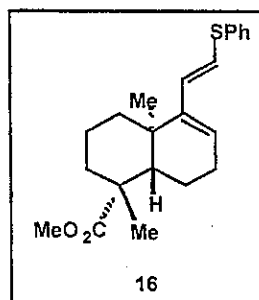
The above mixture was cooled at $-78\text{ }^\circ\text{C}$ and treated with aldehyde **12** (63 mg, 0.2 mmol) in dry THF (1.5 ml). The mixture was allowed to warm slowly to $25\text{ }^\circ\text{C}$, stirred for 8 h and quenched with sodium bicarbonate (10 ml) and water (10 ml). The mixture was extracted with ether (3 x 50 ml) and the organic layers were combined, dried with MgSO_4 , condensed, and subjected to chromatography over silica gel (silica, 10% ether in hexanes) to afford alkene **13**.



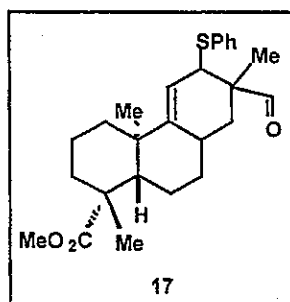
Alcohol 15. A solution of alkyne **9** (1.10 g, 4.2 mmol), thiophenol (1.37 g, 12.4 mmol) and 2,2'-azobisisobutyronitrile (AIBN, 34.5 mg, 0.21 mmol) in xylene (25 ml) was stirred at $110\text{ }^\circ\text{C}$ (under argon) for 18 h. The reaction mixture was cooled to $25\text{ }^\circ\text{C}$ and quenched with aqueous saturated sodium bicarbonate (50 ml). The organic layer was extracted with ethyl ether (3 x 50 ml), collected, dried (MgSO_4), concentrated and residue was chromatographed (silica, 2-5 % ethyl ether in hexane) to afford alcohol **15** (1.35 g, 3.6 mmol, 85.7%); **15**: colorless liquid; $R_f = 0.51$ (silica, 5% ethyl ether in hexanes); $[\alpha]_D^{25} : +24.20$ ($c = 1.0$, benzene); IR (film) ν_{max} 2946.8, 1724.5, 1472.6, 1438.4, 1153.5, 740.0, 690.9; ^1H NMR (500 MHz, CDCl_3) δ 7.20-7.60 (m, 5H), 5.23 (d, 1H, $J = 10.5\text{ Hz}$), 5.12 (d, 1H, $J = 10.0\text{ Hz}$), 3.62 (s, 3H), 2.08-2.24 (m, 2H), 1.16-1.92 (m, 9H), 1.09 (s, 3H), 0.86-1.02 (m, 2H), 0.68 (s, 3H); ^{13}C NMR (100 MHz, CDCl_3) δ 177.8, 151.7, 133.9, 133.7, 128.8, 127.9, 118.2, 54.9, 53.5, 51.1, 44.3, 40.4, 38.1, 37.3, 28.7, 27.7, 25.5, 23.5, 19.5, 18.5.

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10 **Diene 16.** To a solution of alcohol 15 (1.10 g, 2.94 mmol) in hexamethyl phosphoramide (HMPA, 10 ml) was added dropwise phosphorus oxychloride (0.50 g, 3.3 mmol) and the mixture was stirred at 25 °C until clear. Pyridine (0.26 ml, 3.23 mmol) was then added and the mixture was stirred at 150 °C (under argon) for 18 hrs. The reaction mixture was cooled to 25 °C and quenched with aqueous saturated sodium bicarbonate (50 ml). The organic layer was extracted with ethyl ether (3 X 60 ml),
 15 collected, dried (MgSO₄) and concentrated and residue was chromatographed (silica, 2-5 % ethyl ether in hexane) to afford diene 16 (0.85 g, 2.38 mmol, 81%); 16: colorless liquid; *R_f* = 0.60 (silica, 5% ethyl ether in hexanes); $[\alpha]_D^{25}$: -17.30 (*c* = 1.08, benzene); IR (film) ν_{max} 2957.0, 1726.6, 1581.6, 1478.3, 1439.0, 1234.7, 1190.8, 1094.8, 1024.4, 739.1; ¹H NMR (500 MHz, CDCl₃) δ 7.20-7.60 (m, 5H), 6.43 (d, 1H, *J* = 15.0 Hz), 6.36 (d, 1H, *J* = 14.5 Hz), 5.72 (m, 1H), 3.64 (s, 3H), 1.48-2.32 (m, 10H), 1.43 (s, 3H), 1.21 (s, 3H), 1.05 (m, 1H), 0.88 (s, 3H); ¹³C NMR (125 MHz, CDCl₃) δ 177.9, 133.7, 129.1,
 20 128.9, 128.6, 127.5, 126.2, 123.4, 120.9, 52.8, 51.1, 43.7, 37.7, 37.3, 30.2, 28.3, 27.7, 20.1, 19.3, 18.3.

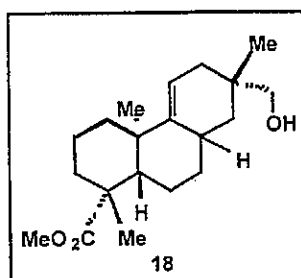


25 **Aldehyde 17.** To a solution of diene 16 (0.51 g, 1.43 mmol) and methacrolein (0.30 g, 4.30 mmol) in dichloromethane (5 ml) at -20 °C was added under argon dropwise tin (IV) chloride (0.29 ml of 1M solution in dichloromethane, 0.29 mmol). The resulting mixture was warmed to 0 °C within 1 hr and
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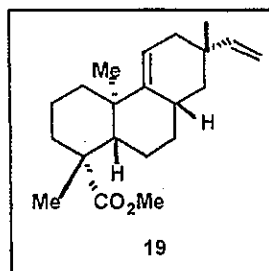
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stirred at 0 °C for 18 h. The reaction was quenched with aqueous saturated sodium bicarbonate (15 ml) and the organic layer was extracted with ethyl ether (3 X 20 ml). The combined organic layers were dried (MgSO₄) and concentrated and residue was chromatographed (silica, 10-15 % ethyl ether in hexane) to afford aldehyde 17 (0.51 g, 1.19 mmol, 83.7%); 4: colorless liquid; *R_f* = 0.48 (silica, 10% ethyl ether in hexanes); $[\alpha]_D^{25}$: +30.0 (*c* = 1.13, benzene); IR (film) ν_{max} 2930.8, 2871.4, 1724.9, 1458.4, 1226.4, 1149.8; ¹H NMR (500 MHz, CDCl₃) δ 9.51 (s, 1H), 7.20-7.60 (m, 5H), 5.57 (m, 1H), 3.65 (s, 3H), 1.20-2.32 (m, 15H), 1.17 (s, 3H), 1.05 (s, 3H), 0.91 (s, 3H); ¹³C NMR (125 MHz, CDCl₃) δ 203.6, 177.9, 153.7, 133.6, 133.5, 128.9, 127.8, 117.1, 51.3, 49.1, 47.7, 44.2, 41.6, 38.7, 38.1, 31.2, 28.3, 27.8, 26.9, 21.7, 20.2, 19.3, 18.6.



Alcohol 18. To a solution of aldehyde 17 (0.50 g, 1.17 mmol) in anhydrous ethanol (5 ml) was added portionwise sodium borohydride (50 mg, 1.32 mmol) and the mixture was stirred for 30 min. Aqueous saturated sodium bicarbonate (10 ml) was then added and the mixture was extracted with ethyl ether (3 x 20 ml). The organic layer was collected, dried (MgSO₄) and concentrated. The residue was redissolved in tetrahydrofuran (5 ml) and treated with excess of Raney Nickel under argon at 65 °C for 10 min. The reaction mixture was filtered, and the filtrate was dried (MgSO₄) and concentrated, and the residue was chromatographed (silica, 2-5 % ethyl ether in hexane) to afford alcohol 18 as a major compound (0.21 g, 0.65 mmol, overall yield 56.1%. Note: the overall yield for the above two reactions is 91%); 18: colorless liquid; *R_f* = 0.39 (silica, 30% ethyl ether in hexanes); $[\alpha]_D^{25}$: -6.70 (*c* = 1.0, benzene); IR (film) ν_{max} 3436.8, 2929.0, 2872.2, 1728.1, 1433.9, 1260.6, 1029.7, 801.6; ¹H NMR (500 MHz, CDCl₃) δ 5.37 (m, 1H), 3.62 (s, 3H), 2.28 (bs, 1H), 2.06-2.20 (m, 2H), 1.20-2.00 (m, 12H), 1.16 (s, 3H), 0.99 (m, 1H), 0.86 (s, 3H), 0.84 (s, 3H); ¹³C NMR (125 MHz, CDCl₃) δ 178.2, 150.4, 116.4, 73.6, 51.2, 47.9, 44.2, 41.9, 38.8, 38.2, 34.3, 33.9, 28.3, 28.2, 27.8, 22.1, 20.3, 20.1, 18.9.

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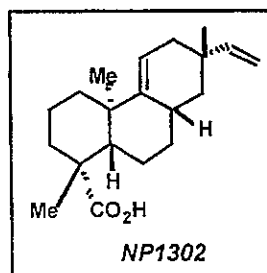
10 **Alkene 19.** To a solution of alcohol 18 (20.0 mg, 0.062 mmol) in dichloromethane (2 ml) was added Dess- Martin periodinane (35 mg, 0.08 mmol) in portions, and the mixture was stirred at 25 °C for 30 min. The reaction was quenched with aqueous saturated sodium bicarbonate (5 ml) and extracted with ethyl ether (3 X 10 ml). The organic layer was collected, dried (MgSO₄) and concentrated. The residue was redissolved in tetrahydrofuran (0.5 ml) and added under argon to a yellow suspension of

15 (methyl) triphenyl-phosphonium bromide (60 mg, 0.17 mmol) and sodium bis(trimethylsilyl) amide (0.14 ml of 1.0 M in THF) in THF (1.5 ml). After stirring at 25 °C for 18 h the mixture was diluted with aqueous saturated sodium bicarbonate (5 ml) and extracted with ethyl ether (3 X 10 ml). The organic layer was collected, dried (MgSO₄), concentrated and residue was chromatographed (silica, 2-5 % ethyl ether in hexane) to afford alkene 19 (16.8 mg, 0.05 mmol, the overall yield for the two-step

20 reactions is 86%); 19: colorless liquid; *R_f* = 0.74 (silica, 5% ethyl ether in hexanes); [α]_D²⁵ : -14.40 (*c* = 0.50, benzene); IR (film) ν_{max} 2929.5, 2873.4, 1726.8, 1637.7, 1460.7, 1376.8, 1225.1, 1150.4, 997.8, 908.7; ¹H NMR (500 MHz, CDCl₃) δ 5.82 (dd, 1H), 5.39 (m, 1H), 4.85-4.94 (dd, 2H), 3.64 (s, 3H), 2.30 (bs, 1H), 2.14 (m, 1H), 2.02 (m, 1H), 1.80-1.98 (m, 2H), 1.68-1.80 (m, 2H), 1.20-1.68 (m, 7H), 1.18 (s, 3H), 0.96-1.08 (m, 2H), 0.95 (s, 3H), 0.88 (s, 3H); ¹³C NMR (125 MHz, CDCl₃) δ 178.3,

25 150.4, 125.6, 116.6, 109.2, 51.2, 47.9, 44.3, 41.9, 41.8, 38.3, 38.2, 37.4, 34.8, 30.2, 29.6, 28.6, 28.4, 27.8, 22.1, 20.4, 19.0.

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Compound of Formula (I). To a solution of alkene 19 (16.8 mg, 0.05 mmol) in N, N-dimethylformamide (2 ml) added lithium bromide (5.0 mg, 0.06 mmol) and the mixture was refluxed at 190 °C for 1 hr. The reaction mixture was then cooled to 25 °C, diluted with H₂O (5 ml) and extracted with ethyl acetate (3 x 10 ml). The organic layer was collected, dried (MgSO₄) and concentrated and
 5 residue was chromatographed (silica, 15-20 % ethyl ether in hexane) to afford Formula (I) (14.9 mg, 0.05 mmol, 92.6%);

Compound of Formula (I) is a colorless liquid; R_f = 0.20 (silica, 30% ethyl ether in hexanes); $[\alpha]^{25}_D$: -6.0 (c = 0.33, benzene); IR (film) ν_{max} 3080.6, 2928.9, 2857.6, 1693.6, 1638.2, 1464.7, 1413.8, 1376.4, 1263.1, 1179.3, 1095.9, 1027.5, 999.2, 909.2, 801.7; ¹H NMR (500 MHz, CDCl₃) δ 5.82 (dd, 10 , 1H), 5.40 (m, 1H), 4.85-4.95 (dd, 2H), 2.30 (bs, 1H), 2.16 (m, 1H), 2.02 (m, 1H), 1.80-1.98 (m, 2H), 1.70-1.84 (m, 2H), 1.10-1.70 (m, 7H), 1.24 (s, 3H), 1.00-1.10 (m, 2H), 0.99 (s, 3H), 0.95 (s, 3H); ¹³C NMR (125 MHz, CDCl₃) δ 150.3, 149.9, 116.7, 109.2, 47.9, 41.8, 41.7, 38.3, 38.2, 37.4, 34.8, 31.8, 28.6, 28.5, 27.7, 22.6, 22.4, 22.1, 20.3, 18.9.

Methods of Using The Invention

15 The *in vitro* and *in vivo* methods described above as part of the present invention also establish the selectivity of a TNF- α or IL-1 modulator. It is recognized that chemicals can modulate a wide variety of biological processes or be selective. Panels of cells based on the present invention can be used to determine the specificity of the candidate modulator. Selectivity is evident, for example, in the field of chemotherapy, where the selectivity of a chemical to be toxic towards cancerous cells, but not
 20 towards non-cancerous cells, is obviously desirable. Selective modulators are preferable because they have fewer side effects in the clinical setting. The selectivity of a candidate modulator can be established *in vitro* by testing the toxicity and effect of a candidate modulator on a plurality of cell lines that exhibit a variety of cellular pathways and sensitivities. The data obtained from these *in vitro* toxicity studies may be extended to animal models, including accepted animal model studies and
 25 human clinical trials, to determine toxicity, efficacy, and selectivity of the candidate modulator.

The present invention also encompasses the compositions, produced by the methods of the invention, in pharmaceutical compositions comprising a pharmaceutically acceptable carrier prepared for storage and subsequent administration, which have a pharmaceutically effective amount of the products disclosed above in a pharmaceutically acceptable carrier or diluent. Acceptable carriers or
 30 diluents for therapeutic use are well known in the pharmaceutical art, and are described, for example, in Remington's Pharmaceutical Sciences, Mack Publishing Co. (A.R. Gennaro edit. 1985). Preservatives, stabilizers, dyes and even flavoring agents may be provided in the pharmaceutical composition. For

example, sodium benzoate, ascorbic acid and esters of p-hydroxybenzoic acid may be added as preservatives. In addition, antioxidants and suspending agents may be used.

These TNF- α or IL-1 modulator compositions may be formulated and used as tablets, capsules, or elixirs for oral administration; suppositories for rectal administration; sterile solutions, suspensions
5 for injectable administration; patches for transdermal administration, and sub-dermal deposits and the like. Injectables can be prepared in conventional forms, either as liquid solutions or suspensions, solid forms suitable for solution or suspension in liquid prior to injection, or as emulsions. Suitable excipients are, for example, water, saline, dextrose, mannitol, lactose, lecithin, albumin, sodium glutamate, cysteine hydrochloride, and the like. In addition, if desired, the injectable pharmaceutical
10 compositions may contain minor amounts of nontoxic auxiliary substances, such as wetting agents, pH buffering agents, and the like. If desired, absorption enhancing preparations (for example, liposomes), may be utilized.

The pharmaceutically effective amount of the TNF- α or IL-1 modulator composition required as a dose will depend on the route of administration, the type of animal being treated, and the physical
15 characteristics of the specific animal under consideration. The dose can be tailored to achieve a desired effect, but will depend on such factors as weight, diet, concurrent medication and other factors which those skilled in the medical arts will recognize.

In practicing the methods of the invention, the products or compositions can be used alone or in combination with one another, or in combination with other therapeutic or diagnostic agents. These
20 products can be utilized *in vivo*, ordinarily in a mammal, preferably in a human, or *in vitro*. In employing them *in vivo*, the products or compositions can be administered to the mammal in a variety of ways, including parenterally, intravenously, subcutaneously, intramuscularly, colonically, rectally, vaginally, nasally or intraperitoneally, employing a variety of dosage forms. Such methods may also be applied to testing chemical activity *in vivo*.

As will be readily apparent to one skilled in the art, the useful *in vivo* dosage to be administered and the particular mode of administration will vary depending upon the age, weight and mammalian
25 species treated, the particular compounds employed, and the specific use for which these compounds are employed. The determination of effective dosage levels, that is the dosage levels necessary to achieve the desired result, can be accomplished by one skilled in the art using routine pharmacological
30 methods. Typically, human clinical applications of products are commenced at lower dosage levels, with dosage level being increased until the desired effect is achieved. Alternatively, acceptable *in vitro* studies can be used to establish useful doses and routes of administration of the compositions identified by the present methods using established pharmacological methods.

In non-human animal studies, applications of potential products are commenced at higher dosage levels, with dosage being decreased until the desired effect is no longer achieved or adverse side effects disappear. The dosage for the products of the present invention can range broadly depending upon the desired affects and the therapeutic indication. Typically, dosages may be between about 10
5 microgram/kg and 100 mg/kg body weight, preferably between about 100 microgram/kg and 10 mg/kg body weight. Alternatively dosages may be based and calculated upon the surface area of the patient, as understood by those of skill in the art. Administration is preferably oral on a daily or twice daily basis.

The exact formulation, route of administration and dosage can be chosen by the individual
10 physician in view of the patient's condition. See for example, Fingl *et al.*, in The Pharmacological Basis of Therapeutics, 1975. It should be noted that the attending physician would know how to and when to terminate, interrupt, or adjust administration due to toxicity, or to organ dysfunctions. Conversely, the attending physician would also know to adjust treatment to higher levels if the clinical response were not adequate (precluding toxicity). The magnitude of an administered dose in the
15 management of the disorder of interest will vary with the severity of the condition to be treated and to the route of administration. The severity of the condition may, for example, be evaluated, in part, by standard prognostic evaluation methods. Further, the dose and perhaps dose frequency, will also vary according to the age, body weight, and response of the individual patient. A program comparable to that discussed above may be used in veterinary medicine.

20 Depending on the specific conditions being treated, such agents may be formulated and administered systemically or locally. A variety of techniques for formulation and administration may be found in Remington's Pharmaceutical Sciences, 18th Ed., Mack Publishing Co., Easton, PA (1990). Suitable administration routes may include oral, rectal, transdermal, vaginal, transmucosal, or intestinal administration; parenteral delivery, including intramuscular, subcutaneous, intramedullary injections, as
25 well as intrathecal, direct intraventricular, intravenous, intraperitoneal, intranasal, or intraocular injections.

For injection, the agents of the invention may be formulated in aqueous solutions, preferably in physiologically compatible buffers such as Hanks' solution, Ringer's solution, or physiological saline buffer. For such transmucosal administration, penetrants appropriate to the barrier to be permeated are
30 used in the formulation. Such penetrants are generally known in the art. Use of pharmaceutically acceptable carriers to formulate the compounds herein disclosed for the practice of the invention into dosages suitable for systemic administration is within the scope of the invention. With proper choice of carrier and suitable manufacturing practice, the compositions of the present invention, in particular, those formulated as solutions, may be administered parenterally, such as by intravenous injection. The

compounds can be formulated readily using pharmaceutically acceptable carriers well known in the art into dosages suitable for oral administration. Such carriers enable the compounds of the invention to be formulated as tablets, pills, capsules, liquids, gels, syrups, slurries, suspensions and the like, for oral ingestion by a patient to be treated.

5 Agents intended to be administered intracellularly may be administered using techniques well known to those of ordinary skill in the art. For example, such agents may be encapsulated into liposomes, then administered as described above. All molecules present in an aqueous solution at the time of liposome formation are incorporated into the aqueous interior. The liposomal contents are both protected from the external micro-environment and, because liposomes fuse with cell membranes, are
10 efficiently delivered into the cell cytoplasm. Additionally, due to their hydrophobicity, small organic molecules may be directly administered intracellularly.

Pharmaceutical compositions suitable for use as herein described include compositions wherein the TNF- α or IL-1 modulators are contained in an effective amount to achieve the TNF- α or IL-1 modulatory purpose. Determination of the effective amounts is well within the capability of those
15 skilled in the art, especially in light of the detailed disclosure provided herein. In addition to the active ingredients, these pharmaceutical compositions may contain suitable pharmaceutically acceptable carriers comprising excipients and auxiliaries which facilitate processing of the active compounds into preparations which can be used pharmaceutically. The preparations formulated for oral administration may be in the form of tablets, dragees, capsules, or solutions. The pharmaceutical compositions of the
20 present invention may be manufactured in a manner that is itself known, for example, by means of conventional mixing, dissolving, granulating, dragee-making, levitating, emulsifying, encapsulating, entrapping, or lyophilizing processes.

Pharmaceutical formulations for parenteral administration include aqueous solutions of the active compounds in water-soluble form. Additionally, suspensions of the active compounds may be
25 prepared as appropriate oily injection suspensions. Suitable lipophilic solvents or vehicles include fatty oils such as sesame oil, or other organic oils such as soybean, grapefruit or almond oils, or synthetic fatty acid esters, such as ethyl oleate or triglycerides, or liposomes. Aqueous injection suspensions may contain substances which increase the viscosity of the suspension, such as sodium carboxymethyl cellulose, sorbitol, or dextran. Optionally, the suspension may also contain suitable stabilizers or
30 agents that increase the solubility of the compounds to allow for the preparation of highly concentrated solutions.

Pharmaceutical preparations for oral use can be obtained by combining the active compounds with solid excipient, optionally grinding a resulting mixture, and processing the mixture of granules, after adding suitable auxiliaries, if desired, to obtain tablets or dragee cores. Suitable excipients are, in

particular, fillers such as sugars, including lactose, sucrose, mannitol, or sorbitol; cellulose preparations such as, for example, maize starch, wheat starch, rice starch, potato starch, gelatin, gum tragacanth, methyl cellulose, hydroxypropylmethyl-cellulose, sodium carboxymethylcellulose, and/or polyvinylpyrrolidone (PVP). If desired, disintegrating agents may be added, such as the cross-linked
5 polyvinyl pyrrolidone, agar, or alginic acid or a salt thereof such as sodium alginate. Dragee cores are provided with suitable coatings. For this purpose, concentrated sugar solutions may be used, which may optionally contain gum arabic, talc, polyvinyl pyrrolidone, carbopol gel, polyethylene glycol, and/or titanium dioxide, lacquer solutions, and suitable organic solvents or solvent mixtures. Dyestuffs or pigments may be added to the tablets or dragee coatings for identification or to characterize different
10 combinations of active compound doses. For this purpose, concentrated sugar solutions may be used, which may optionally contain gum arabic, talc, polyvinyl pyrrolidone, carbopol gel, polyethylene glycol, and/or titanium dioxide, lacquer solutions, and suitable organic solvents or solvent mixtures. Dyestuffs or pigments may be added to the tablets or dragee coatings for identification or to characterize different combinations of active compound doses. Such formulations can be made using
15 methods known in the art (see, for example, U.S. Patent Nos. 5,733,888 (injectable compositions); 5,726,181 (poorly water soluble compounds); 5,707,641 (therapeutically active proteins or peptides); 5,667,809 (lipophilic agents); 5,576,012 (solubilizing polymeric agents); 5,707,615 (anti-viral formulations); 5,683,676 (particulate medicaments); 5,654,286 (topical formulations); 5,688,529 (oral suspensions); 5,445,829 (extended release formulations); 5,653,987 (liquid formulations); 5,641,515
20 (controlled release formulations) and 5,601,845 (spheroid formulations).

Compounds of the present invention can be evaluated for efficacy and toxicity using known methods. For example, the toxicology of a particular compound of the present invention, or of a subset of the compounds of the present invention sharing certain chemical moieties, can be established by determining *in vitro* toxicity towards a cell line, such as a mammalian, and preferably human, cell line.
25 The results of such studies are often predictive of toxicity in animals, such as mammals, or more specifically, humans. Alternatively, the toxicity of particular compounds of the present invention in an animal model, such as mice, rats, rabbits, or monkeys, may be determined using known methods. The efficacy of a particular compound of the present invention may be established using several art recognized methods, such as *in vitro* methods, animal models, or human clinical trials. Art-recognized
30 *in vitro* models exist for nearly every class of condition, including the conditions abated by the present invention, including cancer, cardiovascular disease, and various immune dysfunction. Similarly, acceptable animal models may be used to establish efficacy of chemicals to treat such conditions. When selecting a model to determine efficacy, the skilled artisan can be guided by the state of the art to

choose an appropriate model, dose, and route of administration, and regime. Of course, human clinical trials can also be used to determine the efficacy of a compound of the present invention in humans.

When used as an anti-inflammatory agent, an anti-cancer agent, a tumor-growth-inhibiting compound, or as a means of treating cardiovascular disease, the compounds of Formulae (II), (IIA), and preferably (IIB) can be administered by either oral or a non-oral pathways. When administered orally, it can be administered in capsule, tablet, granule, spray, syrup, or other such form. When administered non-orally, it can be administered as an aqueous suspension, an oily preparation or the like or as a drip, suppository, salve, ointment or the like, when administered via injection, subcutaneously, intraperitoneally, intravenously, intramuscularly, intradermally, or the like. Similarly, it may be administered topically, rectally, or vaginally, as deemed appropriate by those of skill in the art for bringing the compound of the invention into optimal contact with a tumor, thus inhibiting the growth of the tumor. Local administration at the site of the tumor or other disease condition is also contemplated, either before or after tumor resection, or as part of an art-recognized treatment of the disease condition. Controlled release formulations, depot formulations, and infusion pump delivery are similarly contemplated.

The compounds of Formulae (II) and (IIA), and preferably (IIB), when used as an antitumor agent or as a treatment for any other above-identified disease condition, may be orally or non-orally administered to a human patient in the amount of about .0007 mg/day to about 7,000 mg/day of the active ingredient, and more preferably about 0.07 mg/day to about 70 mg/day of the active ingredient at, preferably, one time per day or, less preferably, over two to about ten times per day. Alternatively and also preferably, the compound of the invention may preferably be administered in the stated amounts continuously by, for example, an intravenous drip. Thus, for a patient weighing 70 kilograms, the preferred daily dose of the active anti-tumor ingredient would be about 0.0007 mg/kg/day to about 35 mg/kg/day, and more preferable, 0.007 mg/kg/day to about 0.035 mg/kg/day. Nonetheless, as will be understood by those of skill in the art, in certain situations it may be necessary to administer the anti-tumor compound of the invention in amounts that excess, or even far exceed, the above-stated, preferred dosage range to effectively and aggressively treat particularly advanced or lethal tumors.

To formulate the compound of Formula (II), the compound of Formula (IIA), or the compound of Formula (IIB), as a tumor-growth-inhibiting or anti-viral compound, known surface active agents, excipients, smoothing agents, suspension agents and pharmaceutically acceptable film-forming substances and coating assistants, and the like may be used. Preferably alcohols, esters, sulfated aliphatic alcohols, and the like may be used as surface active agents; sucrose, glucose, lactose, starch, crystallized cellulose, mannitol, light anhydrous silicate, magnesium aluminate, magnesium methasilicate aluminate, synthetic aluminum silicate, calcium carbonate, sodium acid carbonate,

calcium hydrogen phosphate, calcium carboxymethyl cellulose, and the like may be used as excipients; magnesium stearate, talc, hardened oil and the like may be used as smoothing agents; coconut oil, olive oil, sesame oil, peanut oil, soya may be used as suspension agents or lubricants; cellulose acetate phthalate as a derivative of a carbohydrate such as cellulose or sugar, or methyacrylate-methacrylate copolymer as a derivative of polyvinyl may be used as suspension agents; and plasticizers such as ester phthalates and the like may be used as suspension agents. In addition to the foregoing preferred ingredients, sweeteners, fragrances, colorants, preservatives and the like may be added to the administered formulation of the compound of the invention, particularly when the compound is to be administered orally.

10 In the case of using the compound of Formula (II), Formula (IIA), and/or Formula (IIB) as a means of treating skin redness, the compound may alternatively be administered topically as a salve or ointment, in conjunction with a pharmaceutically acceptable carrier.

In the case of using the compound of Formula (II), Formula (IIA), and or Formula (IIB) as a biochemical test reagent, as described above, the compound of the invention may be dissolved in an organic solvent or hydrous organic solvent and directly applied to any of various cultured cell systems. Usable organic solvents include, for example, methanol, methylsulfoxide, and the like. The formulation can, for example, be a powder, granular or other solid inhibitor, or a liquid inhibitor prepared using an organic solvent or a hydrous organic solvent. While a preferred concentration of the compound of the invention for use as a cell cycle inhibitor is generally in the range of about 1 to about 15 100 $\mu\text{g/ml}$, the most appropriate use amount varies depending on the type of cultured cell system and the purpose of use, as will be appreciated by persons of ordinary skill in the art. Also, in certain applications it may be necessary or preferred to persons of ordinary skill in the art to use an amount outside the foregoing range.

The present invention also encompasses the compositions of Formula (II), Formula (IIA), and/or Formula (IIB) in a pharmaceutical compositions comprising a pharmaceutically acceptable carrier. Such compositions may be prepared for storage and for subsequent administration. Acceptable carriers or diluents for therapeutic use are well known in the pharmaceutical art, and are described, for example, in Remington's Pharmaceutical Sciences, Mack Publishing Co. (A.R. Gennaro edit, 1985). For example, such compositions may be formulated and used as tablets, capsules or solutions for oral administration; suppositories for rectal or vaginal administration; sterile solutions or suspensions for injectable administration. Injectables can be prepared in conventional forms, either as liquid solutions or suspensions, solid forms suitable for solution or suspension in liquid prior to injection, or as emulsions. Suitable excipients include, but are not limited to, saline, dextrose, mannitol, lactose, lecithin, albumin, sodium glutamate, cysteine hydrochloride, and the like. In addition, if desired, the 25 30

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injectable pharmaceutical compositions may contain minor amounts of nontoxic auxiliary substances, such as wetting agents, pH buffering agents, and the like. If desired, absorption enhancing preparations (for example, liposomes), may be utilized.

5 The pharmaceutically effective amount of the composition required as a dose will depend on the route of administration, the type of animal being treated, and the physical characteristics of the specific animal under consideration. The dose can be tailored to achieve a desired effect, but will depend on such factors as weight, diet, concurrent medication and other factors which those skilled in the medical arts will recognize.

10 The products or compositions of the invention, as described above, may be used alone or in combination with one another, or in combination with other therapeutic or diagnostic agents. These products can be utilized *in vivo* or *in vitro*. The useful dosages and the most useful modes of administration will vary depending upon the age, weight and animal treated, the particular compounds employed, and the specific use for which these composition or compositions are employed. The magnitude of a dose in the management or treatment for a particular disorder will vary with the severity
15 of the condition to be treated and to the route of administration, and depending on the disease conditions and their severity, the compositions of the present invention may be formulated and administered either systemically or locally. A variety of techniques for formulation and administration may be found in Remington's Pharmaceutical Sciences, 18th ed., Mack Publishing Co., Easton, PA (1990).

20 Various references, publications, and patents are cited herein. To the extent permitted by law, each of these references, publications, and patents is hereby incorporated by reference herein in its entirety.

EXAMPLES

25 The following examples are meant to illustrate specific, preferred embodiments of the invention, and are not meant to limit the scope of protection afforded by the invention. The following examples, specifically Example 1-8, demonstrate that representative compounds of the classes of compounds described herein have been synthesized. Examples 9-17 exhibit, in mammalian cells which present an acceptable preliminary model for human efficacy and safety, treated with increasing doses of the compound of Formula (I), as synthesized in Example 1, and compounds of Formula (IIB), as herein
30 designated TTL1 through TTL4, as synthesized in accordance with the processes of Example 1, and, more particularly, as in Examples 2-5, at concentrations as high as 10 μ g/ml showed similar viability compared to untreated controls indicating that the inhibitory effects of the evaluated compounds on TNF- α synthesis were not mediated by a direct cytotoxic effect.

Subsequent studies with certain preferred compounds of the invention demonstrated that TTL1 exhibited approximately ten (10) fold greater activity compared to THE SYNTHETIC COMPOUND OF FORMULA (I) in inhibiting TNF- α and IL-1 synthesis. TTL3 which contains an additional chemical modification exhibited approximately 100 times greater activity than TTL1. It is important to note that similar to the compound of Formula (I), neither TTL1 nor TTL3 significantly inhibited IL-6 synthesis.

EXAMPLE 1

Stereoselective Synthesis of Compounds of Formulae (I) and (II)

The first stereoselective synthesis of Compound of Formula (I) has been accomplished. Our synthetic plan departs from (-) Wieland-Miescher ketone (107), see Figure 18, and calls upon a Diels-Alder cycloaddition reaction for the construction of the C ring of 101. The described synthesis confirms the proposed stereochemistry of 101 and represents an efficient entry into an unexplored class of biologically active diterpenes.

The root bark of *Acanthopanax koreanum* Nakai (Araliaceae), a deciduous shrub that grows in The Republic of Korea, has been used traditionally as a tonic, sedative, and as a remedy for rheumatism and diabetes. (*Medicinal Plants of East and Southeast Asia*, Perry, L. M.; Metzger, J. Eds.; MIT Press, Cambridge, MA and London, 1980). In their study of the pharmacologically active extracts of this folk medicine, Chung and co-workers have isolated and structurally characterized a novel diterpene, that was subsequently named acanthoic acid (101). ((a) Kim, Y.-H.; Chung, B. S.; Sankawa, U. *J. Nat. Prod.* 1988, 51, 1080-1083; (b) Kang, H.-S.; Kim, Y.-H.; Lee, C.-S.; Lee, J.-J.; Choi, I.; Pyun, K.-H. *Cellular Immunol.* 1996, 170, 212-221; (c) Kang, H.-S.; Song, H. K.; Lee, J.-J.; Pyun, K.-H.; Choi, I. *Mediators Inflamm.* 1998, 7, 257-259).

From the biosynthesis standpoint, 101 belongs to a rather large family of pimaradiene diterpenes, which may be best represented by pimaric acid (102). (Ruzicka, L.; Sternbach, L.; *J. Am. Chem. Soc.* 1948, 70, 2081-2085; Ireland, R. E.; Schiess, P. W. *Tetrahedron Lett.* 1960, 25, 37-43; Wenkert, E.; Buckwalter, B. L. *J. Am. Chem. Soc.* 1972, 94, 4367-4372; Wenkert, E.; Chamberlin, J. W. *J. Am. Chem. Soc.* 1959, 81, 688-693). The structure of the compound of Formula (I) is distinguished by an uncommon connectivity across the rigid tricyclic core, which may be held accountable for its pharmacological profile. Indeed, the recent isolation of this compound has allowed studies into its biological activity and verified its medicinal potential. (Kang, H.-S.; Kim, Y.-H.; Lee, C.-S.; Lee, J.-J.; Choi, I.; Pyun, K.-H. *Cellular Immunol.* 1996, 170, 212-221; Kang, H.-S.; Song, H. K.; Lee, J.-J.; Pyun, K.-H.; Choi, I. *Mediators Inflamm.* 1998, 7, 257-259). More specifically, acanthoic acid was found to exhibit promising anti-inflammatory and antifibrotic activities that presumably arise by inhibiting the production of the pro-inflammatory cytokines: tumor necrosis factor-

alpha (TNF- α) and interleukin-1 (IL-1). See *Tumor Necrosis Factors. The Molecules and their Emerging Role in Medicine*, B. Beutler, Ed.; Raven Press, N.Y. 1992; Aggarwal, B.; Puri, R. *Human Cytokines: Their Role in Disease and Therapy*; Blackwell Science, Inc.: U.S.A., 1995; Thorpe, R.; Mire-Sluis, A. *Cytokines*; Academic Press: San Diego, 1998; Kurzrock, R.; Talpaz, M. *Cytokines: Interleukins and Their Receptors*; Kluwer Academic Publishers: U.S.A., 1995; Szekanecz, Z.; Kosh, A. E.; Kunkel, S. L.; Strieter, R. M. *Clinical Pharmacol.* 1998, 12, 377-390; Camussi, G.; Lupin, E. *Drugs* 1998, 55, 613-620; Newton, R. C.; Decicco, C. P. *J. Med. Chem.* 1999, 42, 2295-2314.

This inhibition was concentration dependent and cytokine-specific since under the same conditions the production of IL-6 or IFN- γ (interferon-gamma) were not affected. In addition, acanthoic acid was found to be active upon oral administration and showed minimal toxicity in experiments performed in mice and rats.

The combination of uncommon structure and promising pharmacological activity displayed by 101 prompted us to extend our synthetic studies, see Xiang, A. X.; Watson, D. A.; Ling, T.; Theodorakis, E. A. *J. Org. Chem.* 1998, 63, 6774-6775; Ling, T.; Xiang, A. X.; Theodorakis, E. A. *Angew. Chem. Int. Ed. Engl.* 1999, 38, 3089-3091, to this family of biologically important metabolites. This example provides a stereoselective total synthesis of (-) acanthoic acid and the compounds of Formula (II) and, as shown in Examples 2-6, provides the basis for the total synthesis of the compounds of Formula (IIB). This Example also confirms the structure and absolute stereochemistry of 101.

The retrosynthetic strategy towards acanthoic acid is illustrated in Figure 20. The C ring of 101 is envisioned to be constructed by a Diels-Alder cycloaddition reaction, thereby revealing dienophile 103 and an appropriately substituted diene, such as 104, as ideal coupling partners. See Oppolzer, W in *Comprehensive Org. Synthesis*, Trost, B. M. Ed.; Oxford, N. Y.; Pergamon Press, 1991, 315-399. This reaction introduces both the unsaturation at the C9-C11 bond and the desired stereochemistry at the C8 and C13 carbons, permitting a convenient branch point between the syntheses of the compounds of Formula (II) and the compounds of Formula (IIB). Diene 104 could be produced by functionalization of ketone 105, whose C4 quaternary center was projected to be formed by a stereocontrolled alkylation of β -ketoester 107. This analysis suggested the use of (-) Wieland-Miescher ketone 107 as a putative starting material. Application of such a plan to the synthesis of acanthoic acid is depicted in Figures 21 and 23, as Schemes 5 and 6. All compounds exhibited satisfactory spectral and analytical data.

The synthesis began with optically pure enone 107, which was readily available through a D-proline-mediated asymmetric Robinson annulation (75-80% yield, >95% ee). See Buchschacher, P.; Fuerst, A.; Gutzwiller, J. *Org. Synth. Coll. Vol. VII* 1990, 368-3372.). Selective ketalization of the C9 ketone group of 107, followed by reductive alkylation across the enone functionality with methyl cyanoformate afforded ketoester 106 in 50% overall yield. See Crabtree, S. R.; Mander, L. N.; Sethi, P.

S. *Org. Synth.* 1992, 70, 256-263. To introduce the desired functionalization at the C4 position, a second reductive alkylation procedure was implemented, *see* Coates, R. M.; Shaw, J. E. *J. Org. Chem.* 1970, 35, 2597-2601; Coates, R. M.; Shaw, J. E. *J. Org. Chem.* 1970, 35, 2601-2605. Compound 106 was first transformed to the corresponding methoxymethyl ether 108, which upon treatment with lithium in liquid ammonia and iodomethane gave rise to ester 110 in 58% overall yield and as a single diastereomer. *See* Welch, S. C.; Hagan, C. P. *Synthetic Comm.* 1973, 3, 29-32; Welch, S. C.; Hagan, C. P.; Kim, J. H.; Chu, P. S. *J. Org. Chem.* 1977, 42, 2879-2887; Welch, S. C.; Hagan, C. P.; White, D. H.; Fleming, W. P.; Trotter, J. W. *J. Amer. Chem. Soc.* 1977, 99, 549-556. The stereoselectivity of this addition arose from the strong preference of the intermediate enolate 109 to undergo alkylation at the less hindered equatorial side.

With the bicyclic core at hand, the C ring was constructed. The C-ring was formed via a Diels-Alder reaction between methacrolein 103, *see* for example, Figure 21, and the sulfur-containing diene 104. The synthesis of 104 was initiated with an acid-catalyzed deprotection of the C9 ketal of 110, followed by alkylation of the resulting ketone 105 with lithium acetylide-ethylene diamine complex. *See* Das, J.; Dickinson, R. A.; Kakushima, M.; Kingston, G. M.; Reid, G. R.; Sato, Y.; Valenta, Z. *Can. J. Chem.* 1984, 62, 1103-1111). This sequence afforded alkyne 111 as an 8:1 diastereomeric mixture at C9 (in favor of the isomer shown) and in 86% overall yield. At this point, the diastereofacial selectivity of the Diels-Alder reaction was evaluated, as was the overall feasibility of using a non-functionalized diene, such as 112. To this end, the diastereomeric mixture of propargyl alcohols 111 was partially reduced (H₂, Lindlar's catalyst) and dehydrated (BF₃·Et₂O) to produce diene 112 in 90% yield. (Coisne, J.-M.; Pecher, J.; Declercq, J.-P.; Germain, G.; van Meerssche, M. *Bull. Soc. Chim. Belg.* 1980, 89, 551-557). The Diels-Alder cycloaddition between 112 and methacrolein (103) under neat conditions at 25°C, afforded in quantitative yield a mixture of two diastereomeric aldehydes that were separated after reduction with sodium borohydride. The resulting alcohols 114 and 115 were transformed to the corresponding *p*-bromobenzoate esters (compounds 116 and 117 respectively), which upon recrystallization with dichloromethane/ethanol yielded crystals suitable for X-Ray analysis (Figure 22).

The results of the X-ray analyses established that the tricyclic system had the expected stereochemistry at the C4 position and confirmed that the Diels-Alder reaction proceeded with exclusive *endo* orientation. Methacrolein was shown to produce *exo* Diels Alder products when reacting with cyclopentadiene: Kobuke, Y.; Fueno, T.; Furukawa, J. *J. Am. Chem. Soc.* 1970, 92, 6548-6553. This surprising observation was rationalized based on the steric repulsion exhibited by the methyl group: Yoon, T.; Danishefsky, S. J.; de Gala, S. *Angew. Chem. Int. Ed. Engl.* 1994, 33, 853-855). Second, after reduction, the major product of the cycloaddition was shown to be alcohol 114,

which had the desired stereochemistry at the C8 center, thereby demonstrating a strong preference of diene 112 to undergo reaction with 103, *see* for example, Figure 21, from the α -face (bottom side attack). Moreover, these data indicated that synthesis of acanthoic acid would require an inversion in the orientation of the incoming dienophile.

5 As discussed in Example 2-8, below, absent inversion of the incoming dienophile, the wholly novel compounds of Formula (IIB) were synthesized. The choice of an appropriate substituted dienophile allows essentially limitless selection of the R₁₁ and R₁₂ groups of the compounds of Formula (IIB).

10 The inversion of the dienophile required for the synthesis of the compound of Formula (I), its naturally occurring analogs, and the compounds of Formula (II) and (IIA), was accomplished by altering the atomic orbital coefficients at the termini of the diene, supporting the use of a heteroatom-containing diene, such as 104, during the cycloaddition. *See generally* Overman, L. E.; Petty, C. B.; Ban, T.; Huang, G. T. *J. Am. Chem. Soc.* 1983, 105, 6335-6338; Trost, B. M.; Ippen, J.; Vladuchick, W. C. *J. Am. Chem. Soc.* 1977, 99, 8116-8118; Cohen, T.; Kozarych, Z. *J. Org. Chem.* 1982, 47, 4008-
15 4010; Hopkins, P. B.; Fuchs, P. L. *J. Org. Chem.* 1978, 43, 1208-1217; Petrzilka, M.; Grayson, J. I. *Synthesis*, 1981, 753-786). The construction of diene 104 and its utilization for the synthesis of 101 is shown in Figure 23, Scheme 6.

Compound 104 was produced by a radical addition of thiophenol onto alkyne 111 (Greengrass, C. W.; Hughman, J. A.; Parsons, P. J. *J. Chem. Soc. Chem. Commun.* 1985, 889-890), followed by
20 POCl₃-mediated dehydration of the resulting allylic alcohol (Trost, B. M.; Jungheim, L. N. *J. Am. Chem. Soc.* 1980, 102, 7910-7925; Mehta, G.; Murthy, A. N.; Reddy, D. S.; Reddy, A. V. *J. Am. Chem. Soc.* 1986, 108, 3443-3452) (2 steps, 70% yield). Interestingly, this dehydration was also attempted with BF₃•Et₂O, but proved ineffective in this case. With a substantial amount of 104 at hand, we investigated the Diels-Alder reaction, using 103 as the dienophile. Several thermal- (-78 to 80°C) and
25 Lewis acid-(BF₃•Et₂O, TiCl₄, AlCl₃ and SnCl₄) catalyzed Diels-Alder conditions were tested. Best results were obtained with SnCl₄ in methylene chloride at -20°C and afforded aldehyde 118 in 84% yield as a 4.2:1 mixture of diastereomers. To simplify the product characterization and allow adequate separation, this mixture was reduced with NaBH₄ and reductively desulfurized using Raney Ni. Alcohols 119 and 120 were thus obtained in 91% overall yield. The structure of these compounds was
30 assigned by comparison to the products isolated from the reaction between 103 and 112. Treatment of the major diastereomer 120 with Dess-Martin periodinane, followed by Wittig methylenation installed the alkene functionality at the C13 center and produced 121 in 86% overall yield. The C-19 carboxylic acid was then deprotected. Exposure of 121 to LiBr in refluxing DMF gave rise to acanthoic acid 101 in 93% yield via an S_N²-type displacement of the acyloxyl functionality. *See* Bennet, C. R.; Cambie,

R. C. *Tetrahedron* 1967, 23, 927-941. Synthetic 101 had identical spectroscopic and analytical data with those reported for the natural product.

This Example provides a concise, stereoselective synthesis of Compound 101. The synthetic strategy is highlighted by the implementation of a Diels-Alder reaction between diene 104 and methacrolein (103), which set the stereochemistry at the C13 and C8 carbon centers. The described synthesis of 101 requires fourteen steps (starting with enone 107) and proceeds in approximately 9% overall yield. The overall efficiency and versatility of our strategy sets the foundation for the preparation of designed analogs with improved pharmacological profiles.

EXAMPLES 2-8

10 Stereoselective Synthesis of Compounds of Formula (IIB)

The procedure outline in Example 1, and depicted in Figure 23. Scheme 6, may be modified or truncated to yield the compounds of Formula (II) or Formula (IIB).

EXAMPLE 2

The compound herein designated TTL4 was synthesized by following the procedures of Example 1, as depicted in Figure 21, to yield compound 114, herein designated TTL4.

EXAMPLE 3

The compound herein designated TTL2 was synthesized by following the procedures of Example 1, as depicted in Figure 21, to yield compound 114. Similar to the reaction depicted in Figure 23, step (h), the compound 114 was then reacted with 3.0 equivalents LiBr, in DMF, at 160°C, for approximately three hours, to a yield of approximately 93% of the compound herein designated TTL2.

EXAMPLE 4

The compound herein designated TTL3 was synthesized by following the procedures as depicted in Figure 14, to yield compound 13. This compound is herein designated TTL3.

EXAMPLE 5

25 The compound herein designated TTL1 was synthesized by following the procedures as depicted in Figure 14, to yield compound 13. This compound is herein designated TTL1.

EXAMPLE 6

30 A compound of Formulae (IIB) wherein R₁₅ is a hydrogen and R₉ and R₁₅ are separately selected from the group consisting of C₁-C₆ alkyl, and C₁-C₆ substituted alkyl is synthesized by following the procedures therefor of Example 1, except that the dienophile is selected from one of the compound of Formulae (III) wherein R₁₅ is a hydrogen and R₉ and R₁₅ are separately selected from the group consisting of C₁-C₆ alkyl, and C₁-C₆ substituted alkyl, as in this Example.

EXAMPLE 7

Specifically, a compound of Formulae (IIB) wherein R_{14} is a hydrogen and R_9 and R_{15} are separately selected from the group consisting of C_1 - C_6 alkyl, and C_1 - C_6 substituted alkyl is synthesized by following the procedures therefor of Example 1, except that the dienophile is selected from one of the compound of Formulae (III) wherein R_{14} is a hydrogen and R_9 and R_{15} are separately selected from the group consisting of C_1 - C_6 alkyl, and C_1 - C_6 substituted alkyl, as in this Example.

EXAMPLE 8

A compound of Formulae (IIB) wherein R_{14} is a hydrogen, and R_9 and R_{15} are separately selected from C_2 - C_6 alkenyl, C_2 - C_6 substituted alkenyl, C_1 - C_6 alcohol, and C_5 - C_6 aryl, is synthesized by following the procedures therefor of Example 1, except that the dienophile is selected from one of the compound of Formulae (III) wherein R_{14} is a hydrogen and R_9 and R_{15} are separately selected from C_2 - C_6 alkenyl, C_2 - C_6 substituted alkenyl, C_1 - C_6 alcohol, and C_5 - C_6 aryl, as in this Example.

EXAMPLES 9 - 17Materials and methods.

Murine macrophage cells RAW 264.7 (1×10^6 /ml) were pretreated for 30-60 minutes with varying doses of the synthetic compound of Formula (I), the synthetic compound of formula (I) and a panel of analogs (diluted in 0.5% DMSO) prior to stimulation with various agents such as lipopolysaccharide (LPS) or a gram positive agent like heat-killed *Staph aureus* (SAC). Supernatants collected over a 72-hour period will be assayed for the levels of TNF- α , IL-1, IL-6, IL-10, IL-18 and other cytokines either by elisa or bioassay. Additional studies to evaluate the effects of the synthetic compound of Formulae (I), (II), (IIA) and (IIB) on specific cytokine signaling pathways such as Caspase-activity (Nr-1, Nr.3), NF-kB, MAP-kinase activity (P38, ERK and JNK) will also be performed.

Results

Preclinical studies demonstrated that murine RAW 264.7 cells treated with increasing doses of the synthetic compounds of Formulae (I) and (IIB), specifically those designated TTL1 and TTL3 herein, at concentrations as high as 10ug/ml showed similar viability compared to untreated controls indicating that the inhibitory effects of the synthetic compounds of Formulae (I) and (IIB) on TNF- α synthesis were not mediated by a direct cytotoxic effect.

Subsequent studies with the compound of Formula (I) as synthesized according to Example 1, TTL1 (as synthesized according to Example 2) and TTL3 (as synthesized according to Example 4) demonstrated that TTL1 exhibited approximately 10 fold greater activity compared to the compound of Formula (I) as synthesized according to Example 1 in inhibiting TNF- α and IL-1 synthesis. TTL3, as synthesized according to Example 4, contains an additional chemical modification exhibited

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approximately 100 times greater activity than TTL1, as synthesized according to Example 2. It is noted that similar to the compound of Formula (I) as synthesized according to Example 1, neither analog TTL1 nor TTL3 significantly inhibited IL-6 synthesis. TTL1 exhibited a ten (10)-fold greater activity compared to the compound of Formula (I) as synthesized according to Example 1 in inhibiting TNF- α and IL-1 synthesis.

TTL3 which contains an additional chemical modification exhibited approximately 100 times greater activity than TTL1. It is again important to note that similar to the compound of Formula (I) as synthesized according to Example 1, neither analog significantly inhibited IL-6 synthesis.

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TABLE 1
Inhibition of LPS-Induced TNF- α Synthesis by the Compound of Formula (I) and TTL1

	Formula (I) (0.1 μ g/ml)	Formula (I) (1 μ g/ml)	Formula (I) (10 μ g/ml)	TTL1 (0.1 μ g/ml)	TTL1 (1 μ g/ml)	TTL1 (5.4 μ g/ml)
LPS	120	67	50	57	60	38
TNF- α (ng/ml)	108					

TABLE 2
Inhibition of SAC-Induced TNF- α Synthesis by the Compound of Formula (I) and TTL1

	Formula (I) (0.1 μ g/ml)	Formula (I) (1 μ g/ml)	Formula (I) (10 μ g/ml)	TTL1 (0.1 μ g/ml)	TTL1 (1 μ g/ml)	TTL1 (5.4 μ g/ml)
SAC	385	275	165	250	285	150
TNF- α (ng/ml)	410					

TABLE 3
Inhibition of SAC-Induced IL-1 Synthesis by the Compound of Formula (I) and TTL1

	Formula (I) (0.1 μ g/ml)	Formula (I) (1 μ g/ml)	Formula (I) (10 μ g/ml)	TTL1 (0.1 μ g/ml)	TTL1 (1 μ g/ml)	TTL1 (5.4 μ g/ml)
SAC	700	1050	350	950	400	300
IL-1 α (pg/ml)	1350					

TABLE 4
The Compound of Formula (I) and TTL1 Do Not Inhibit SAC-Induced IL-6 Synthesis

	Formula (I) (0.1 μ g/ml)	Formula (I) (1 μ g/ml)	Formula (I) (10 μ g/ml)	TTL1 (0.1 μ g/ml)	TTL1 (1 μ g/ml)	TTL1 (5.4 μ g/ml)
SAC	75	90	80	83	86	65
IL-6 (ng/ml)	65					

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TABLE 5
TTL3 Inhibits SAC-Induced TNF- α Synthesis

TNF- α (ng/ml)	Unstimulated	SAC	0.001 μ g/ml	0.01 μ g/ml	0.1 μ g/ml	1 μ g/ml	10 μ g/ml
	5	375	80	75	85	60	80

TABLE 6
TTL3 Inhibits SAC-Induced IL-1 Synthesis

IL-1 α (pg/ml)	Unstimulated	SAC	0.001 μ g/ml	0.01 μ g/ml	0.1 μ g/ml	1 μ g/ml	10 μ g/ml
	0	650	200	220	190	180	170

TABLE 7
Inhibition of LPS-Induced TNF- α Synthesis by TTL3 (TNF- α (ng/ml))

LPS (1 μ g/ml) + TTL3 (μ g/ml)					
LPS alone	(1 x 10 ⁻⁷)	(1 x 10 ⁻⁶)	(1 x 10 ⁻⁵)	(1 x 10 ⁻⁴)	(1 x 10 ⁻³)
88	41	18	10	15	13
					4

TABLE 8
TTL3 Inhibits Mortality After LPS/D-Gal Administration

Treatment*	Mortality 24 hours	Mortality 48 hours
LPS/D-Gal	10/10	10/10
LPS/D-Gal + DMSO	8/10	9/10
LPS/D-Gal + TTL3	2/10	2/10

* All treatments were i.p., TTL3 administration 45 minutes prior to LPS

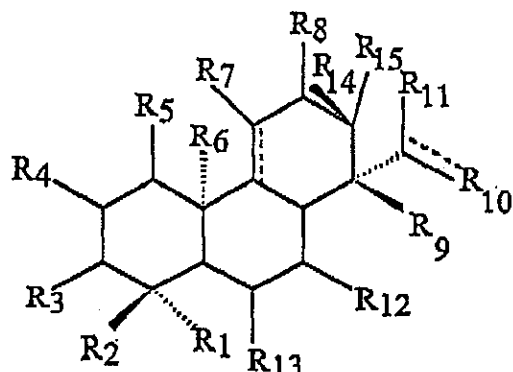
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While specific embodiments of the invention have been shown and described in detail and exemplified to illustrate the application of and the principles of the invention, it will be understood that the invention may be embodied otherwise without departing from such principles.

WHAT IS CLAIMED IS:

1. A compound having the following chemical structure:



wherein:

R_1 is selected from the group consisting of hydrogen, a halogen, COOH , $\text{C}_1\text{-C}_{12}$ carboxylic acids, $\text{C}_1\text{-C}_{12}$ acyl halides, $\text{C}_1\text{-C}_{12}$ acyl residues, $\text{C}_1\text{-C}_{12}$ esters, $\text{C}_1\text{-C}_{12}$ secondary amides, $(\text{C}_1\text{-C}_{12})(\text{C}_1\text{-C}_{12})$ tertiary amides, $\text{C}_1\text{-C}_{12}$ alcohols, $(\text{C}_1\text{-C}_{12})(\text{C}_1\text{-C}_{12})$ ethers, $\text{C}_1\text{-C}_{12}$ alkyls, $\text{C}_1\text{-C}_{12}$ substituted alkyls, $\text{C}_2\text{-C}_{12}$ alkenyls, $\text{C}_2\text{-C}_{12}$ substituted alkenyls, and $\text{C}_5\text{-C}_{12}$ aryls;

R_2 and R_9 are each separately selected from hydrogen, a halogen, $\text{C}_1\text{-C}_{12}$ alkyl, $\text{C}_1\text{-C}_{12}$ substituted alkyls, $\text{C}_2\text{-C}_{12}$ alkenyl, $\text{C}_2\text{-C}_{12}$ substituted alkenyl, $\text{C}_2\text{-C}_{12}$ alkynyl, $\text{C}_1\text{-C}_{12}$ alcohol, $\text{C}_1\text{-C}_{12}$ acyl, and $\text{C}_5\text{-C}_{12}$ aryl;

$R_3\text{-R}_5$, R_7 , R_8 , and $R_{11}\text{-R}_{13}$ are each separately selected from hydrogen, a halogen, $\text{C}_1\text{-C}_{12}$ alkyl, $\text{C}_1\text{-C}_{12}$ substituted alkyls, $\text{C}_2\text{-C}_{12}$ alkenyl, $\text{C}_2\text{-C}_{12}$ substituted alkenyl, $\text{C}_2\text{-C}_{12}$ alkynyl, and $\text{C}_5\text{-C}_{12}$ aryl;

R_6 is selected from hydrogen, a halogen, $\text{C}_1\text{-C}_{12}$ alkyl, $\text{C}_1\text{-C}_{12}$ substituted alkyls, $\text{C}_2\text{-C}_{12}$ alkenyl, $\text{C}_2\text{-C}_{12}$ substituted alkenyl, and $\text{C}_2\text{-C}_{12}$ alkynyl;

R_{10} is selected from hydrogen, a halogen, CH_2 , $\text{C}_1\text{-C}_6$ alkyl, $\text{C}_1\text{-C}_6$ substituted alkyl, $\text{C}_2\text{-C}_6$ alkenyl, $\text{C}_2\text{-C}_6$ substituted alkenyl, $\text{C}_1\text{-C}_{12}$ alcohol, and $\text{C}_5\text{-C}_{12}$ aryl; and

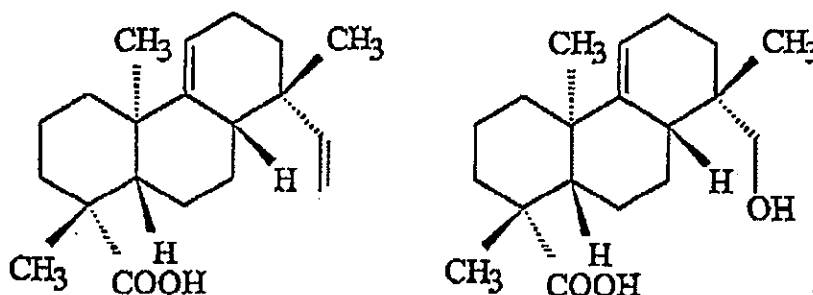
R_{14} and R_{15} are separately selected from hydrogen, a halogen, CH_2 , $\text{C}_1\text{-C}_6$ alkyl, $\text{C}_1\text{-C}_6$ substituted alkyl, $\text{C}_2\text{-C}_6$ alkenyl, $\text{C}_2\text{-C}_6$ substituted alkenyl, $\text{C}_1\text{-C}_6$ alcohol, and $\text{C}_5\text{-C}_6$ aryl;

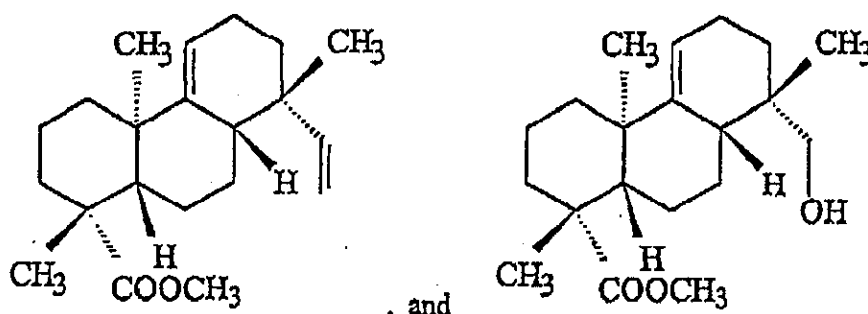
wherein the compound includes the prodrug esters of the above compounds, and the acid-addition salts thereof.

2. The compound of Claim 1, wherein:

R_1 is selected from hydrogen, a halogen, and $\text{C}_1\text{-C}_{12}$ carboxylic acids, $\text{C}_1\text{-C}_{12}$ acyl halides, $\text{C}_1\text{-C}_{12}$ acyl residues, $\text{C}_2\text{-C}_{12}$ esters, $\text{C}_2\text{-C}_{12}$ secondary amides, $(\text{C}_1\text{-C}_{12})(\text{C}_1\text{-C}_{12})$ tertiary amides, $\text{C}_2\text{-C}_{12}$ alcohols, $(\text{C}_1\text{-C}_{12})(\text{C}_1\text{-C}_{12})$ ethers, $\text{C}_2\text{-C}_{12}$ alkyls, $\text{C}_1\text{-C}_{12}$ substituted alkyls, $\text{C}_2\text{-C}_{12}$ alkenyls, $\text{C}_2\text{-C}_{12}$ substituted alkenyls, and $\text{C}_5\text{-C}_{12}$ aryls.

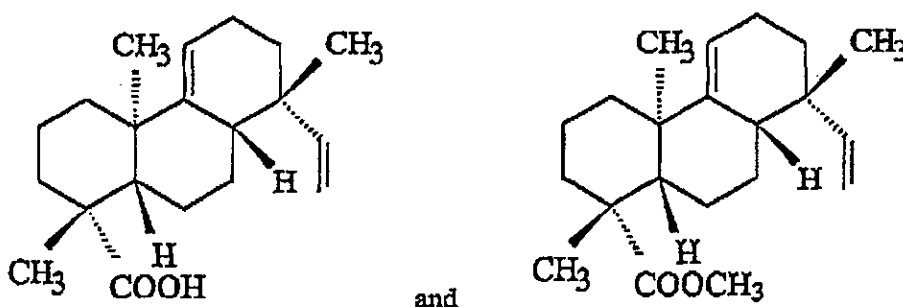
3. The compound of Claim 1, wherein:
 R_1 is selected from the group consisting of hydrogen, a halogen, COOH , $\text{C}_1\text{-C}_6$ carboxylic acids, $\text{C}_1\text{-C}_6$ acyl halides, $\text{C}_1\text{-C}_6$ acyl residues, $\text{C}_1\text{-C}_6$ esters, $\text{C}_1\text{-C}_6$ secondary amides, $(\text{C}_1\text{-C}_6)(\text{C}_1\text{-C}_6)$ tertiary amides, $\text{C}_1\text{-C}_6$ alcohols, $(\text{C}_1\text{-C}_6)(\text{C}_1\text{-C}_6)$ ethers, $\text{C}_1\text{-C}_6$ alkyls, $\text{C}_1\text{-C}_{16}$ substituted alkyls, $\text{C}_2\text{-C}_6$ alkenyls, $\text{C}_2\text{-C}_{12}$ substituted alkenyls, and $\text{C}_5\text{-C}_6$ aryls.
4. The compound of Claim 1, wherein R_1 is selected from the group consisting of $\text{C}_2\text{-C}_6$ esters and $\text{C}_1\text{-C}_6$ acyl residues.
5. The compound of Claim 1, wherein R_1 is selected from the group consisting of $\text{C}_2\text{-C}_6$ esters.
6. The compound of Claim 1, wherein R_{10} is selected from the group consisting of $\text{C}_2\text{-C}_6$ alkyl groups and $\text{C}_2\text{-C}_6$ alkenyl groups.
7. The compound of Claim 1, wherein $R_3\text{-R}_5$, R_7 , R_8 , $R_{11}\text{-R}_{15}$ is each hydrogen.
8. The compound of Claim 7, wherein $R_3\text{-R}_5$, R_7 , R_8 , $R_{11}\text{-R}_{15}$ is each hydrogen; R_2 , R_6 , and R_9 are each methyl; and R_{10} is CH_2 .
9. The compound of Claim 1, wherein R_{15} is hydrogen, and R_{14} is selected from hydrogen, a halogen, and $\text{C}_1\text{-C}_{12}$ carboxylic acids, $\text{C}_1\text{-C}_{12}$ acyl halides, $\text{C}_1\text{-C}_{12}$ acyl residues, $\text{C}_2\text{-C}_{12}$ esters, $\text{C}_2\text{-C}_{12}$ secondary amides, $(\text{C}_1\text{-C}_{12})(\text{C}_1\text{-C}_{12})$ tertiary amides, $\text{C}_2\text{-C}_{12}$ alcohols, $(\text{C}_1\text{-C}_{12})(\text{C}_1\text{-C}_{12})$ ethers, $\text{C}_2\text{-C}_{12}$ alkyls, $\text{C}_1\text{-C}_{12}$ substituted alkyls, $\text{C}_2\text{-C}_{12}$ alkenyls, $\text{C}_2\text{-C}_{12}$ substituted alkenyls, and $\text{C}_5\text{-C}_{12}$ aryls.
10. The compound of Claim 1, wherein R_{15} is hydrogen, and R_{14} is selected from hydrogen, a halogen, $\text{C}_2\text{-C}_6$ alcohols, $\text{C}_2\text{-C}_6$ alkyls, $\text{C}_1\text{-C}_6$ substituted alkyls, $\text{C}_2\text{-C}_6$ alkenyls, $\text{C}_2\text{-C}_6$ substituted alkenyls, and $\text{C}_5\text{-C}_6$ aryls.
11. The compound of Claim 1, wherein the compound is selected from the group consisting of





and the prodrug esters and acid-addition salts thereof.

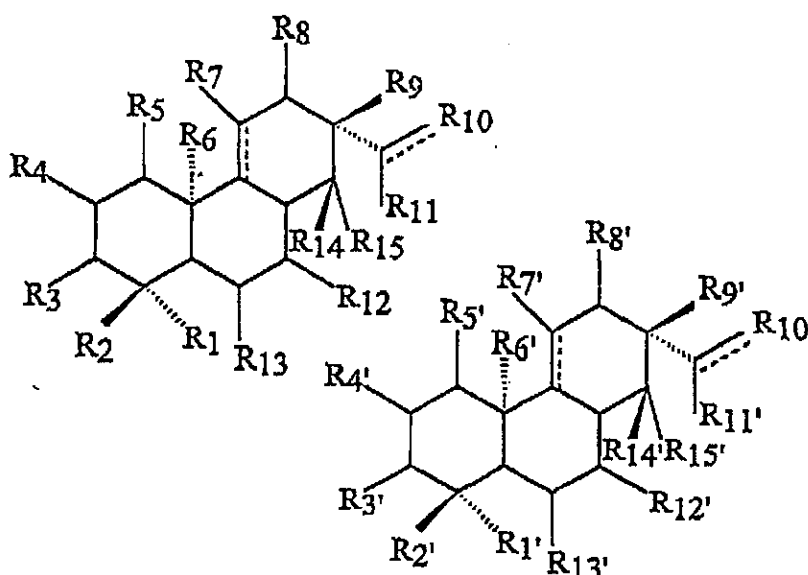
12. The compound of Claim 1, wherein the compound is selected from the group consisting of



and the prodrug esters and acid-addition salts thereof.

13. The compound of Claim 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 or 12, for use in treating a disease condition selected from the group consisting of inflammation, tuberculous pleurisy, rheumatoid pleurisy, cancer, cardiovascular disease, skin redness, diabetes, transplant rejection, otitis media (inner ear infection), sinusitis and viral infection.

14. A compound having the following chemical structure:



wherein R₁ and R₂ are covalently linked, and wherein

R_1 and $R_{1'}$ are each selected from the group consisting of C_1 - C_6 alkyls, C_1 - C_6 substituted alkyls, C_2 - C_6 alkenyls, and C_2 - C_6 substituted alkenyls;

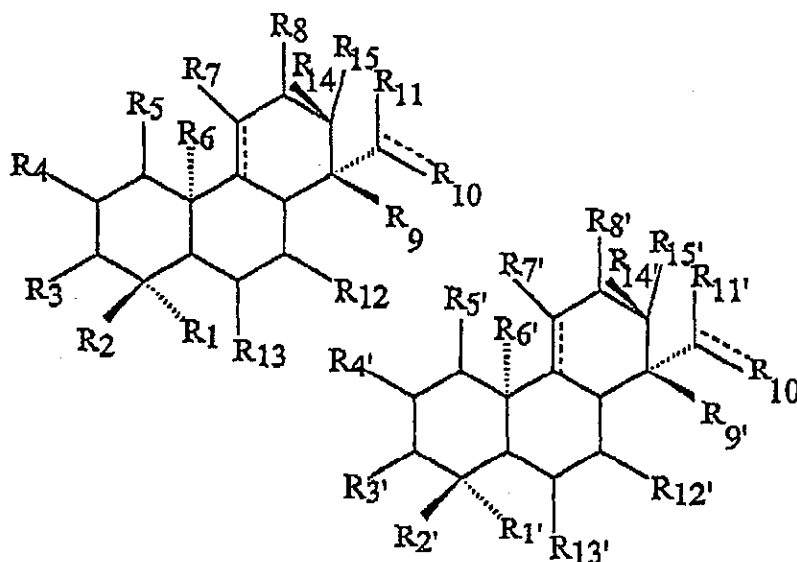
R_2 and R_9 and $R_{2'}$ and $R_{9'}$ are each separately selected from hydrogen, a halogen, C_1 - C_{12} alkyl, C_1 - C_{12} substituted alkyls, C_2 - C_{12} alkenyl, C_2 - C_{12} substituted alkenyl, C_2 - C_{12} alkynyl, and C_1 - C_{12} acyl, and C_5 - C_{12} aryl;

R_3 - R_5 , R_7 , R_8 , and R_{11} - R_{15} and $R_{3'}$ - $R_{5'}$, $R_{7'}$, $R_{8'}$, and $R_{11'}$ - $R_{15'}$ are each separately selected from hydrogen, a halogen, C_1 - C_{12} alkyl, C_1 - C_{12} substituted alkyls, C_2 - C_{12} alkenyl, C_2 - C_{12} substituted alkenyl, C_2 - C_{12} alkynyl, and C_5 - C_{12} aryl;

R_6 and $R_{6'}$ are independently selected from hydrogen, a halogen, C_1 - C_{12} alkyl, C_1 - C_{12} substituted alkyls, C_2 - C_{12} alkenyl, C_2 - C_{12} substituted alkenyl, and C_2 - C_{12} alkynyl; and

R_{10} and $R_{10'}$ are independently selected from hydrogen, a halogen, CH_2 , C_1 - C_6 alkyl, C_1 - C_6 substituted alkyl, C_2 - C_6 alkenyl, C_2 - C_6 substituted alkenyl, C_1 - C_{12} alcohol, and C_5 - C_{12} aryl.

15. A compound having the following chemical structure:



wherein R_1 and $R_{1'}$ are covalently linked, and wherein

R_1 and $R_{1'}$ are each selected from the group consisting of C_1 - C_6 alkyls, C_1 - C_6 substituted alkyls, C_2 - C_6 alkenyls, and C_2 - C_6 substituted alkenyls;

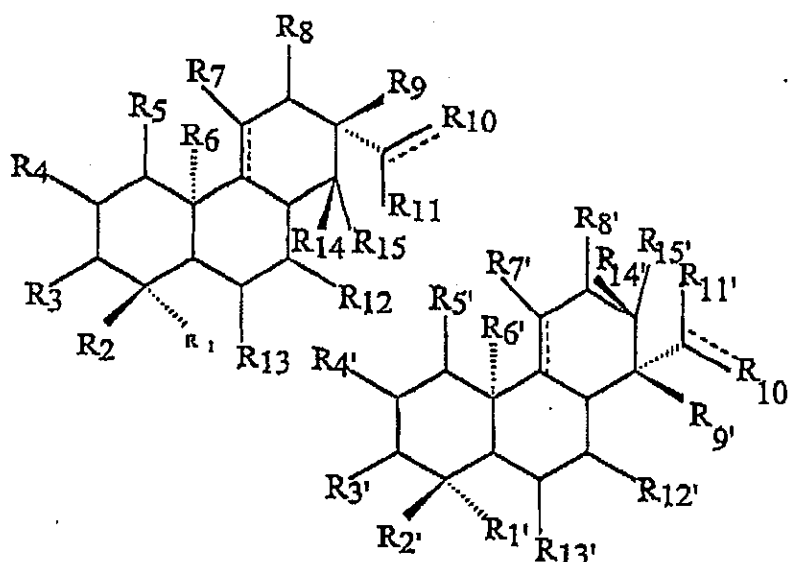
R_2 and R_9 and $R_{2'}$ and $R_{9'}$ are each separately selected from hydrogen, a halogen, C_1 - C_{12} alkyl, C_1 - C_{12} substituted alkyls, C_2 - C_{12} alkenyl, C_2 - C_{12} substituted alkenyl, C_2 - C_{12} alkynyl, and C_1 - C_{12} acyl, and C_5 - C_{12} aryl;

R_3 - R_5 , R_7 , R_8 , and R_{11} - R_{15} and $R_{3'}$ - $R_{5'}$, $R_{7'}$, $R_{8'}$, and $R_{11'}$ - $R_{15'}$ are each separately selected from hydrogen, a halogen, C_1 - C_{12} alkyl, C_1 - C_{12} substituted alkyls, C_2 - C_{12} alkenyl, C_2 - C_{12} substituted alkenyl, C_2 - C_{12} alkynyl, and C_5 - C_{12} aryl;

R_6 and R_6' are independently selected from hydrogen, a halogen, C_1 - C_{12} alkyl, C_1 - C_{12} substituted alkyls, C_2 - C_{12} alkenyl, C_2 - C_{12} substituted alkenyl, and C_2 - C_{12} alkynyl; and

R_{10} and R_{10}' are independently selected from hydrogen, a halogen, CH_2 , C_1 - C_6 alkyl, C_1 - C_6 substituted alkyl, C_2 - C_6 alkenyl, C_2 - C_6 substituted alkenyl, C_1 - C_{12} alcohol, and C_5 - C_{12} aryl.

16. A compound having the following chemical structure:



wherein R_1 and $R_{1'}$ are covalently linked, and wherein

R_1 and $R_{1'}$ are each selected from the group consisting of C_1 - C_6 alkyls, C_1 - C_6 substituted alkyls, C_2 - C_6 alkenyls, and C_2 - C_6 substituted alkenyls;

R_2 and R_9 and R_2' and R_9' are each separately selected from hydrogen, a halogen, C_1 - C_{12} alkyl, C_1 - C_{12} substituted alkyls, C_2 - C_{12} alkenyl, C_2 - C_{12} substituted alkenyl, C_2 - C_{12} alkynyl, and C_1 - C_{12} acyl, and C_5 - C_{12} aryl;

R_3 - R_5 , R_7 , R_8 , and R_{11} - R_{15} and R_3' - R_5' , R_7' , R_8' , and R_{11}' - R_{15}' are each separately selected from hydrogen, a halogen, C_1 - C_{12} alkyl, C_1 - C_{12} substituted alkyls, C_2 - C_{12} alkenyl, C_2 - C_{12} substituted alkenyl, C_2 - C_{12} alkynyl, and C_5 - C_{12} aryl;

R_6 and R_6' are independently selected from hydrogen, a halogen, C_1 - C_{12} alkyl, C_1 - C_{12} substituted alkyls, C_2 - C_{12} alkenyl, C_2 - C_{12} substituted alkenyl, and C_2 - C_{12} alkynyl; and

R_{10} and R_{10}' are independently selected from hydrogen, a halogen, CH_2 , C_1 - C_6 alkyl, C_1 - C_6 substituted alkyl, C_2 - C_6 alkenyl, C_2 - C_6 substituted alkenyl, C_1 - C_{12} alcohol, and C_5 - C_{12} aryl.

17. The compound of Claim 14, 15 or 16, wherein

R_1 and $R_{1'}$ together comprise the structure:



wherein n is a positive integer no greater than eight.

18. The compound of Claim 14, 15 or 16, for use in the treatment of a disease condition selected from the group consisting of tuberculous pleurisy, rheumatoid pleurisy, cancer, cardiovascular disease, skin redness, diabetes, transplant rejection, otitis media (inner ear infection), sinusitis and viral infection.

19. A synthetic method of making the compound of Claims 1-11 or 12, comprising the steps of:

performing a Diels-Alder reaction reacting a diene having two or more rings with a dienophile compound to yield a resultant compound have three or more rings; and
yielding the compound of Claims 1-11 or 12.